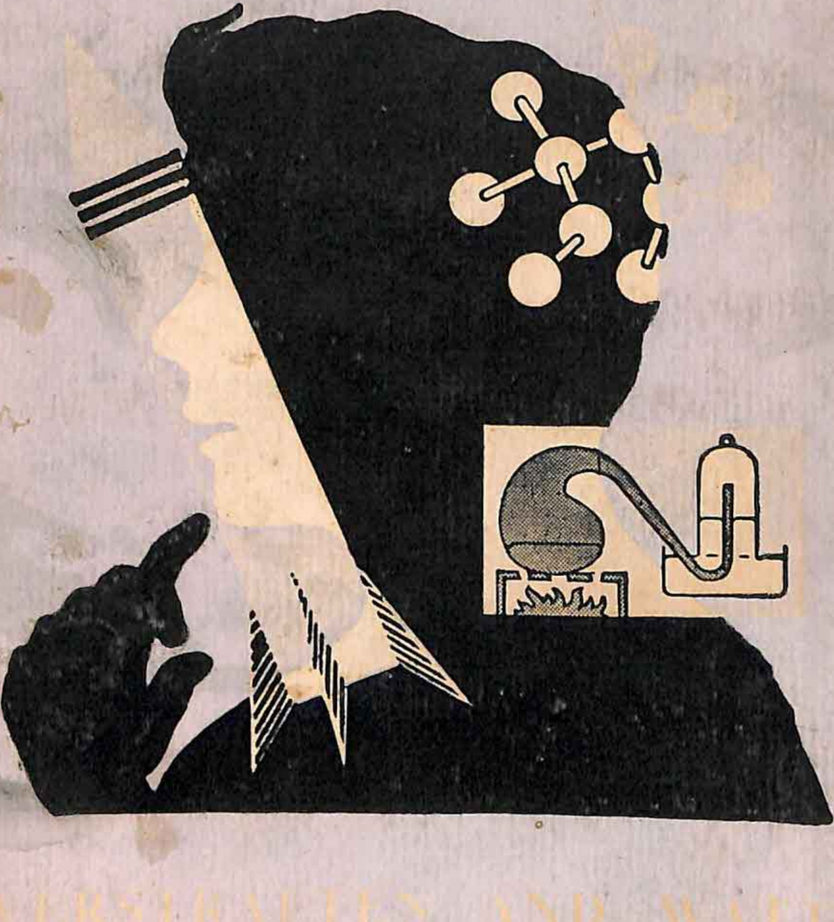
SCIENCE IN EVERYDAY LIFE

BOOK FOUR



VERSHEATTES AND WATTS

STATE INSTITUTE OF EDUCATION
BANIPUR

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SCIENCE IN EVERYDAY LIFE

BOOK FOUR

2018

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AND

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FOREWORD

As a result of the advances in Science and Technology the vocational foundations of the structure of Society are changing and, therefore, it is essential for all Secondary School pupils to be familiar with certain scientific ideas which underlie progressive thought and activity at all levels.

The purpose of this series of General Science books is to provide such pupils with a broad basic knowledge of scientific facts.

Mere instruction in Science will not capture what is termed the 'spirit of science'. Westaway rightly points out: "The spirit of science cannot be weighed and measured even if weighing and measuring are necessary for tracking it down. It is not enough to track it down, it must be captured...." The authors have succeeded, I believe, in presenting scientific ideas in a manner which will not only instruct but interest pupils and thus help them to capture the spirit of Science.

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M.P., B.A., H.DIP.ED. (DUBLIN), T.D.,
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and
Secretary to the Council for the Indian School Certificate Examination (University of Cambridge Local Examinations Syndicate)

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SCIENCE IN EVERYDAY LIFE
FOR SENIORS

Books I, II, III and IV
Workbooks I, II, III and IV to accompany
each text-book

Teacher's Manual including Key to Workbooks

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PREFACE

THIS course in General Science is meant to provide the pupils studying in Secondary and Higher Secondary Schools with a scientific outlook; it should make them aware of the impact of science and technology on their natural surroundings and on society.

Besides taking stock of the natural phenomena occurring around them, the pupils should become acquainted with the scientific methods which enable man to acquire an intellectual grasp of these phenomena and put them to use for the benefit and comfort of human society. Only in this way can the citizen of tomorrow be properly trained for the challenge of the complex life of this technological age that is awaiting him.

This is the object of the General Science course prescribed as a core subject for all pupils studying in Higher Secondary Schools.

The present course is based on, and follows closely, the syllabus of General Science as given in the 'Draft Syllabus for Higher Secondary Schools' issued by the All-India Council of Secondary Education, Government of India, New Delhi.

The actual break-up and the details of the course are exactly in accordance with the Syllabus in General Science adopted by the Council for the Indian School Certificate Examination and the West Bengal Board of Secondary Education for the schools under their control.

SCIENCE IN EVERYDAY LIFE is divided into five parts so as to meet the requirements of pupils in schools under the control of the West Bengal Board of Secondary Education studying General Science as a core subject from Class VI to Class X. Furthermore, the series comprises four books to meet the requirements of pupils in schools under the control of the Council for the Indian School Certificate Examination studying General Science as a core subject from Class (Standard) VII to Class (Standard) X.

The attention of teachers is specially drawn to the item Chapter Activities at the end of every chapter. These should be taken up along with the matter treated in the body of the chapter, as they describe simple experiments illustrating the explanations given in the chapter. Above all, these activities will make the pupils take an active and personal part in exploring their surroundings and acquiring an orderly understanding of the day to day life of the world and the community in which they live.

A. Verstraeten
N. A. Watts

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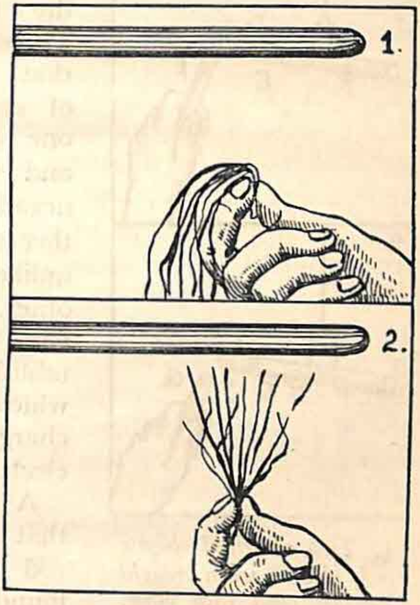
CHAPTER I

ELECTRICITY IN MODERN LIFE

ONE of the main revolutionising factors in our modern civilisation is the great facility with which power in the form of electricity can be provided even at very long distances and used in an infinite variety of ways. In this chapter you will read about the fundamental principles of electricity.

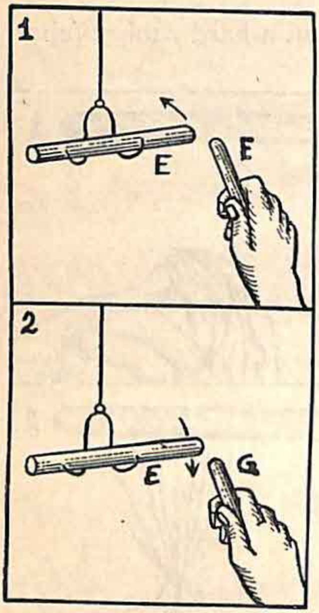
Electrification by Friction. When a hard rubber (ebonite) rod or a plastic rod has been rubbed with a woollen cloth or a bit of fur, it attracts small bits of paper or other light objects. A glass rod rubbed with silk shows the same properties. Such objects, which on being rubbed with another object, acquire the property of attracting objects, are said to be electrified. The name is derived from the Greek word *elektron* which means amber, which in ancient times was one of the original objects showing this property after it had been rubbed. This is common experience nowadays. When on a dry day you



Electricity by rubbing.
1, *Before electrification.*
2, *After the ebonite rod has been electrified by rubbing, it attracts the tuft of paper strips.*

pass a plastic comb through your hair, and your hair is dry and not oily, you may hear a crackling noise, and on passing the comb back over your hair you will see your hair stand up, as it is attracted by the comb electrified by rubbing. The crackling noise is due to tiny electric sparks jumping from the hair to the points of the comb.

Two electrified ebonite rods, when brought together repel each other, the same happens with two electrified glass rods. But when an electrified ebonite rod is brought close to an electrified glass rod, the two attract each other. Therefore, scientists conclude that there must be two types of electricity. They called the one on the glass rod positive and that on the ebonite rod negative. They concluded further that like charges repel and unlike charges attract each other. By rubbing various objects with various materials they established two series of materials which on being rubbed are charged with positive or negative electricity.



1, *Two electrified ebonite rods (E, E) when brought together repel each other.* 2, *When an electrified ebonite rod (E) is brought close to an electrified glass rod (G), the two rods attract each other.*

A further interesting fact is that after rubbing an ebonite rod with fur, the fur is also found to attract small bits of paper, it is also electrified, and the sign of its charge is positive, the opposite of that on the ebonite rod. So also after passing the plastic comb through your hair, when dry, both are charged with electricity of opposite signs.

Therefore, when two objects are brought in close contact, as in the process of rubbing, a redistribution of electricity takes place between the two bodies, so that after they are again separated, one has one type of electricity and the other the opposite type. This can be fairly easily understood if we admit, as is now generally accepted, that all matter contains plenty of electrified particles, some positive, some negative, in general the two just balancing each other so that the body is electrically neutral. The negative electrified particles are the electrons discovered by an English physicist J. J. Thomson in 1897, the charge of an electron is the smallest charge, which cannot be further split up, its mass is only $\frac{1}{1840}$ that of a hydrogen atom. Each atom is supposed to contain a certain mass carrying a positive charge, with a number of electrons circling around it, whose total charge is equal to that of the positive one, except for the sign. Some atoms rather easily part with one or two of their electrons, whereas some other atoms readily capture some extra electrons, this depends on the particular structure of each atom. When two substances of these two different types of atoms are brought in close contact, a number of electrons will easily pass from one substance to the other, so that when the substances are again separated, one will have an excess of electrons, hence have a net negative charge, and the other being short of its normal supply of electrons, will have a net positive charge.

Insulators and Conductors. A brass rod when rubbed with cloth or fur, does not seem to be electrified as it does not attract bits of paper. If, however, you fix a brass rod into a glass tube, and, holding the glass in your hand, you rub the brass with flannel, you will find that it is electrified. The explanation is that brass and other metals, when electrified by rubbing, readily allow the electric charges to move from the rubbed end to the other end held in the hand, so that the charge passes in the body.

Therefore we conclude that there are two types of substances: good and bad conductors of electricity, just as there are good and bad conductors of heat; glass, ebonite, plastics and so on, are bad conductors of electricity, they are also called insulators. If a good conductor like a metal sphere, is to keep its electric charge, it must be mounted on an insulating support.

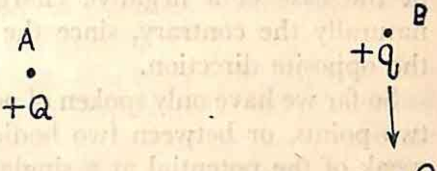
The good conducting property of metals is explained by the assumption based on valid facts that the atoms of these substances have some electrons only loosely held by the atoms. Therefore, in metallic conductors quite a number of electrons are readily available for carrying electric charges from one side of the conductor to the other. If, for example, a positive charge is developed at one end, the electrons will be attracted towards that end, if on the contrary, a negative charge is developed at one end, the electrons will be repelled away from it, and so the positive or negative electric charge will equivalently be carried from one end to the other.

Electricity Can Do Work. If, after having electrified objects by friction, we keep them at some distance from each other, they will tend to repel or attract each other, hence there is a possibility of getting work done, there is energy available, and we call it potential energy, because the available energy depends on the respective positions of the electrified bodies. This is very similar to the case of raising an object from the ground to a higher level; once it is there it has a tendency to come down, being attracted by the earth, and in doing so might be made to do some work.

The amount of work done by a falling body depends on its mass, as well as on its height. So also in the case of attraction or repulsion between electrified bodies, the work that can be done under the action of the electric forces, depends on the quantity of electricity on the bodies and on the distance between them.

Scientists have defined unit of quantity of electricity as being the quantity which being at unit distance from a similar quantity repels it with unit force (1 dyne); this being a very small quantity, for practical purposes a larger unit has been chosen, which is called the coulomb.

Potential Difference. Considering the work done by attracting or repelling electrified bodies, we are particularly concerned with getting a definite expression for the amount of work done when electric charges move from one point to another.

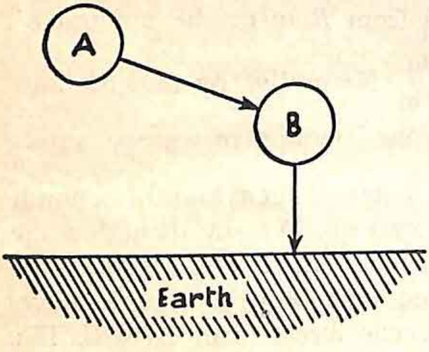


Suppose at *A* there is a small body carrying a positive electric charge *Q* and at *B* another small body carrying a positive charge *q*; the two repel each other. If *A* is fixed and *B* can move, then when *B* moves, work will be done. Suppose that an amount of work *w* is done when the body moves from *B* to *C*, that means a certain amount of energy is no longer available and the potential energy has decreased by *w*. If in the same circumstances unit positive charge moved from *B* to *C*, the amount of work done would be $w_1=\frac{w}{q}$. Naturally, by moving unit charge from *C* back to *B*, an amount of energy $w_1=\frac{w}{q}$ would have to be done by an external agent and this amount of energy would now be stored up. We say then that the potential difference between the points *B* and *C* is measured by w_1, the work done when unit positive charge moves under the action of the electric forces from *B* to *C*. If a charge q moves from B to C the work done is q times the potential difference between the two. Here again we must choose some proper unit, scientists have chosen as a practical unit the volt, which corresponds to a potential difference between two points such that when a charge of one coulomb moves from one to the other the amount of work done is one joule (10^7 ergs).

Naturally if the work done when moving in a particular direction is negative, it means that an outside agent must supply work to move unit charge from the first to the second point against the electric forces.

When the potential difference is positive we say that the first point is at a higher potential than the second, if the potential difference is negative then it is the reverse. We also say that a positive charge tends to move from a point at a higher potential to a point at a lower potential; in the case of a negative charge, say the electron, it is naturally the contrary, since the electric forces will act in the opposite direction.

So far we have only spoken of potential difference between two points, or between two bodies; but we also frequently speak of the potential at a single point, or the potential of a single body. For all practical purposes, the potential at point, or of a body, is the amount of work that would be done when unit charge of electricity moves from that point, or that body, to the earth, which for all practical purposes is considered as electrically neutral. If then, we consider two charged bodies A and B, their potentials, with reference to the earth are, say, V_A and



V_B, then we may consider unit charge moving from A to B, and from B to the earth, so that the work done when unit charge is moving from A to B is $V_A—V_B$. Therefore, the potential difference between two bodies is the difference between their respective potentials with reference to a neutral body like the earth.

Reversing the above reasoning we see that to carry unit charge from a neutral point to a body at a potential V will require an amount of work equal to V and to carry q charges an amount of work qV will be needed.

All this is naturally very similar to the case of water stored up in dams: to carry a weight w of water up to a height h requires an amount of work equal to wh, and if that weight of water drops through a height h the work done is wh. If a weight w of water drops from a level h_1 above the ground to another lower level h_2 above the ground the work done is $w\ (h_1—h_2)=wh_1—wh_2$, that is the difference between the work done when the water drops from the respective heights to the ground.

Condensers. The potential of a body charged with electricity depends first of all on the quantity of electricity, and also on other factors such as the size of the body, and the bodies surrounding it. Thus, if the same quantity of electricity is put on two spheres of different radii, the potentials of these spheres will be in the inverse ratio of their radii; it means that the larger the body, the greater the quantity of electricity required to raise its potential by a given amount. In fact, the term 'capacity' of a conductor indicates the quantity of electricity required to increase its potential by one unit, say one volt.

It is also found that the capacity of a conductor increases when it is surrounded by other conductors which are earth-connected, the distance between the two being as small as possible and filled by some insulating material, like a thin sheet of ebonite or mica. It means that in this case a larger amount of electricity can be stored without unduly raising the potential. Such an arrangement of two conductors, say two plates, separated by a thin layer of an insulating material is called a condenser; its capacity, meaning the quantity of electricity required to raise the potential difference between the two plates by one unit, depends directly on the areas of the two plates and varies inversely as the distance between them. Such condensers are of very common use in many electric mechanisms, in particular in wireless transmitting and receiving sets.

Lightning. In Book I you have read about the great number of thunderstorms that occur every year over the world. It was mentioned there that lightning consists of an electric discharge between an electrified cloud and the earth or between two electrified clouds. Although the distance over which this discharge takes place is very large, at times, one or more miles, the discharge is possible because of the very high potential difference between the two points between which the discharge takes place. As a matter of fact the path of the discharge is gradually made ready by a process called ionisation of the air. In the air there are always a few electrified particles present. These particles are violently attracted by the electrified cloud, and on their way these particles collide with other gas particles. These in turn, due to the collision, lose one or more electrons and so are electrified. So that in no time quite a large quantity of electrified particles called ions are produced which will readily conduct the electric discharge from the cloud to the earth or to another cloud with an electric charge of opposite sign.

How does a cloud become electrified? Scientists have not been able to offer a fully satisfactory explanation. What is known is that generally, in a thundercloud there is an accumulation of negative charges at the lower portion, and of positive charges at the top. On the other hand, the cloud consists of millions and millions of water drops and tiny ice crystals. These particles are in constant and violent agitation by turbulent currents taking place in the cloud. It is suggested that the continuous rubbing of the ice crystals, and the breaking up of the water droplets is responsible for the separation of positive and negative electric charges, the positive ones being carried up by the air currents, the negative charges being brought down by the heavier particles.

Electric Currents. When two conductors at different potentials are connected by a wire or in some other manner: the wire gets heated, a magnetic needle placed near the wire is deflected; if the two conductors are connected by a boy holding one and then touching the other he gets a shock; if a wire is first fixed to each conductor and then the free ends of the two wires are dipped a small distance apart in a solution of salt or of hydrochloric acid a chemical decomposition takes place in the solution. In each case, the electricity flowing from the conductor at a higher potential to that of a lower potential produces these various effects: heating, magnetic, physiological and chemical. These, of course, are various ways of spending the energy produced when electricity flows from one conductor to the other.

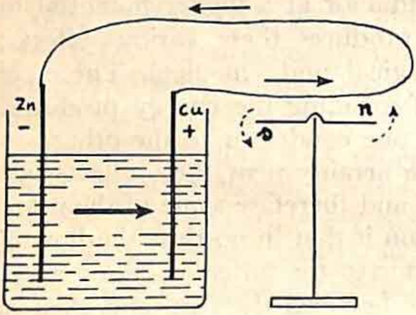
However, with the above arrangement these effects last only a fraction of a second, and therefore some of them are difficult to observe, the reason is that in no time the flow of electricity from one conductor to the other has done away with the potential difference between the two, and then of course the flow of electricity stops.

What is required therefore, is some arrangement by which two conductors are maintained at different potentials while the electricity flows from one to the other through a wire connecting them or in some other manner.

Actually the flow of electricity in a conductor consists of a flow of electrons from the conductor at a lower potential to the conductor at a higher potential, hence it means that we require an arrangement by which a fresh supply of electrons is constantly produced at the conductor at a lower potential while at the other conductor, at a higher potential, the electrons arriving there are constantly removed. Any arrangement realising this is called an electric generator.

The first practical way of realising this was devised by an Italian scientist named Alexander Volta in 1800, in the apparatus named after him, the Voltaic cell.

The Voltaic Cell. When a zinc and copper rod, dipping in a dilute solution of sulphuric acid, are connected by a wire, an electric current flows from the copper rod to the zinc rod, showing the various effects that have been mentioned above. Even before connecting the two rods by a wire, it can be shown that the copper rod is positively charged and the zinc rod negatively charged. The flow of electric current from one to the other through the connecting wire will go on for quite some time, the copper and zinc rods being kept positively and negatively charged by a chemical reaction occurring inside the solution. In fact, we have here an electric current flowing in a closed circuit. Outside, the current flows from the copper to the zinc rod, while inside the solution the current flows from the zinc to the copper rod producing a chemical decomposition



Voltaic cell and circuit with magnetic needle near wire. Unbroken arrows show the direction of the electric current. Broken arrows show the direction in which the magnetic needle deflects.
Zn, zinc; Cu, copper.

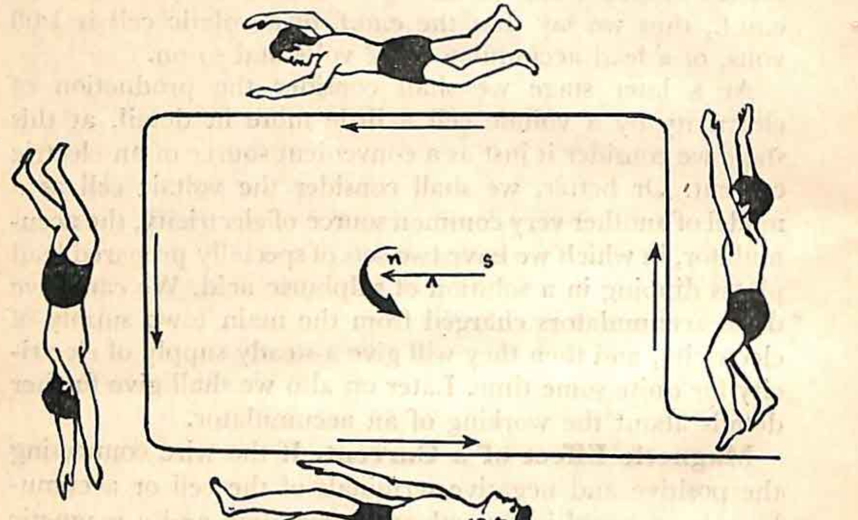
that maintains the current and supplies the energy spent by the current. The potential difference between the two terminals of a generator responsible for the current, is called the electro-motive force of the generator usually written as e.m.f., thus we say that the e.m.f. of a volatic cell is 1·08 volts, of a lead accumulator is 2 volts and so on.

At a later stage we shall consider the production of electricity by a voltaic cell a little more in detail, at this stage we consider it just as a convenient source of an electric current. Or better, we shall consider the voltaic cell as a model of another very common source of electricity, the accumulator, in which we have two sets of specially prepared lead plates dipping in a solution of sulphuric acid. We can have these accumulators charged from the main town supply of electricity, and then they will give a steady supply of electricity for quite some time. Later on also we shall give further details about the working of an accumulator.

Magnetic Effect of a Current. If the wire connecting the positive and negative terminals of the cell or accumulator is arranged in a north-south direction and a magnetic needle pivoted about a vertical axis is brought above and near the wire, the needle is deflected; if it is placed below the wire, the needle is deflected in the opposite direction. If now a portion of the connecting wire is made vertical, and a magnetic needle is slowly taken around the wire, it is found that the needle tends to remain tangent to the circle along which it is moved.

It is clear therefore that the electric current flowing in a wire acts on the poles of a magnet just as another magnet would act on it, we say therefore that an electric current produces a magnetic field all around it. A Danish scientist named Hans Oersted was the first to draw attention to this very important phenomenon in 1819.

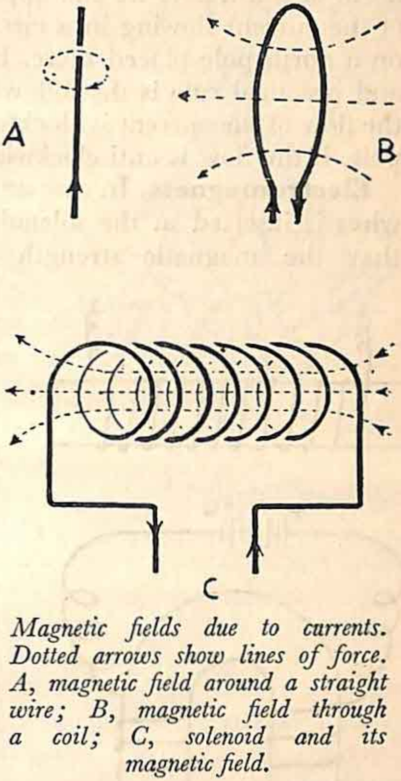
A year later a French physicist named André Ampére, formulated a clear rule for finding the direction in which a magnetic pole is acted upon by an electric current. It is his famous rule of the swimmer: imagine a man swimming along the wire in the direction of the current, and facing



Ampére's rule.

the magnetic needle, then the action of the current tends to deflect the north pole to his left. Naturally therefore in the above example of the vertical wire, as the needle is taken round the wire, the swimmer has to turn steadily in order to face the needle, and his left will turn all the while and so also will the north pole of the needle, keeping it tangent to the circle around the wire.

In case you bend a portion of the wire into a circular loop and place a small magnetic needle at its centre, applying Ampére's rule you will find that the electric current all along the circular loop acts on the north pole at the centre along the same direction and perpendicular to the plane of the loop. Therefore, the needle will tend to place itself perpendicular to the plane; the words 'will tend' are used because there is always the action of the earth's magnetic field acting on the needle and which may act in a different direction.

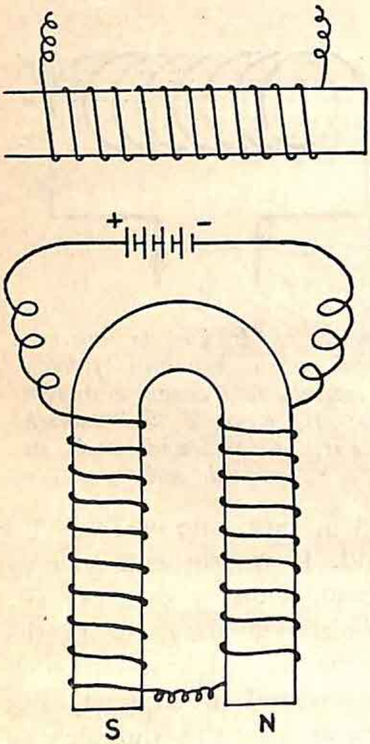


Magnetic fields due to currents. Dotted arrows show lines of force. A, magnetic field around a straight wire; B, magnetic field through a coil; C, solenoid and its magnetic field.

If we take a glass tube or rod and wind on it a series of coils of insulated wire, and pass an electric current through it, the magnetic force of the currents in each coil will act along the same direction. We have in fact the equivalent of a bar magnet, it is called a solenoid; taking an ordinary magnet and bringing its north pole to each of the ends of the solenoid in turn, one end will be attracted and the other repelled. If we suspend such a solenoid so that its axis can rotate about a vertical axis, we shall see that it tends to place itself along the north-south direction like an ordinary magnet. Making two such solenoids, with or without a glass rod as support, and passing a current in each of them, we have the equivalent of two magnets, and can perform with them all the experiments that are performed with ordinary magnets.

To know which end of the solenoid corresponds to the north or south pole we can apply Ampére's rule to this case of the current flowing in a circular coil to find how it acts on a north pole placed there. However, a more convenient and practical rule is the following: when facing the coil, if the flow of the current is clockwise then this end is the south pole, if the flow is anti-clockwise this end is the north pole.

Electromagnets. In case an iron rod, or a bunch of iron wires is inserted in the solenoid along its axis, it is found that the magnetic strength of the solenoid is greatly increased. We have then what is called an electromagnet.

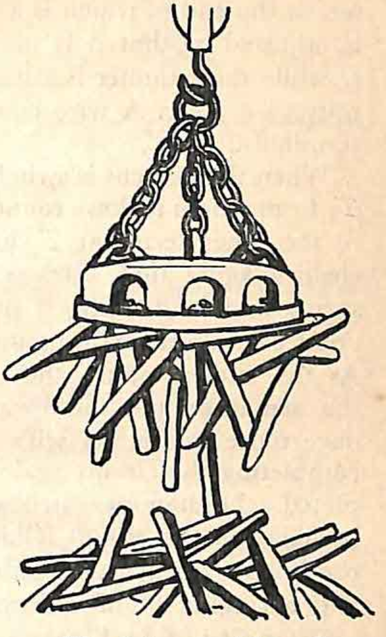


Electromagnets.
Above: bar magnet.
Below: horse-shoe magnet.

The core of an electromagnet may be in the form of a straight rod or in the form of a horse-shoe. In the case of a horse-shoe magnet the winding of the coil is continuous so that the current circulates in a clockwise direction at one end and in an anti-clockwise direction at the other end.

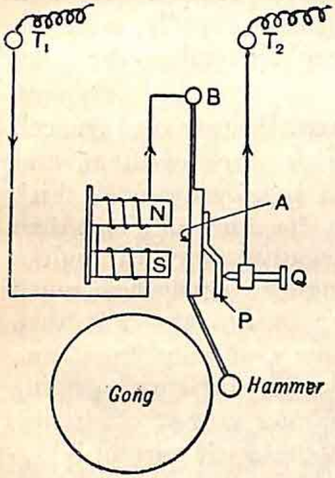
The magnetic power of an electromagnet is greatly increased by using special iron alloys containing nickel and aluminium, by increasing the number of turns of wire around the soft iron core and by using a strong current.

Electromagnets are used with cranes for lifting and transferring iron parts. In iron works, they are used for breaking large pieces of cast iron into smaller ones. When used for such a purpose a heavy iron ball is lifted by an electromagnet attached to a crane. The ball is dropped on the pieces of iron by merely breaking the circuit of the electromagnet. One common use of such magnets is in the construction of electric bells.



The electromagnet is used for lifting scrap iron.

Electric Bell. This instrument depends for its action on the principle of the electromagnet. The electromagnet *NS* is of the horse-shoe type. One end of the coil which is wound around the electromagnet is connected to the terminal T_1 while the other is connected to a metal strip *P*. This strip is connected to a soft iron armature *A* that is joined to the pivot *B* by a rod of springy material. The armature carries a



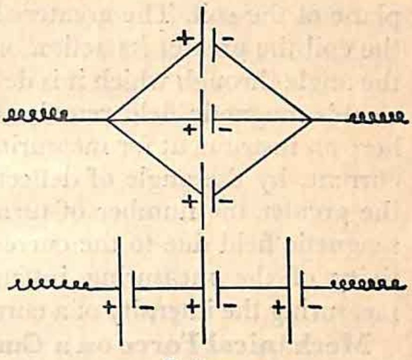
Electric bell.

A, armature; B, pivot; NS, electromagnet; P, metal strip; Q, screw; T_1 *and* T_2*, terminals.*

rod at the end of which is a small hammer. The metal strip is adjusted so that it is normally in contact with a screw Q while the hammer is adjusted so that it is in close proximity of a gong. A wire connects the screw Q to a second terminal T_2.

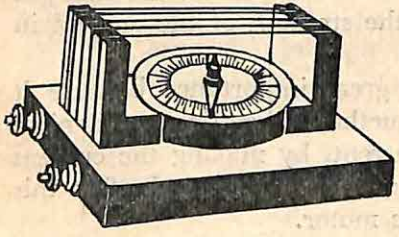
When the current is switched on, it enters at the terminal T_1 from where it flows round the coils of the electromagnet, to the other terminal T_2 and so back to the mains. The electromagnet then attracts the armature attached to the spring and in drawing it pulls the strip P away from the point of the screw Q thus breaking the circuit at this point. As the current stops, the electromagnet ceases to attract the armature and the spring draws it back so that it is once more in contact with the point of the screw Q thus completing the circuit again. Each time the circuit is completed, the hammer strikes the gong. The making and breaking of the circuit follow each other rapidly, with the result that the hammer vibrates rapidly against the gong and a ringing sound is heard.

Intensity of an Electric Current. If, instead of one cell or one accumulator, we take two or three of them, and joining all the positive poles on one side by means of thick wire, and all the negative poles on the other side and then connect the joint positive and negative poles through a solenoid, we shall find that its magnetic strength is much greater than when only one cell or accumulator was used. This is easy to explain, because now electricity flows from each of the two or three positive plates to the corresponding negative plates, hence there is a greater flow of electricity, and the magnetic effect of this greater electric current is also intensified. We say then that the intensity of the electric current is increased, and that the magnetic effect of a current varies with the intensity of the current. This arrangement of connecting the positive poles of several accumulators together and similarly the corresponding negative poles, is referred to as 'connected in parallel'. When, on the contrary, the positive poles of the second battery is connected to the negative of the first and the positive of the third connected to the negative of the second, then we say that they are 'connected in series', and we refer to the whole set as a battery. In this case the potential difference between the positive pole of the first and the negative pole of the last is practically equal to the sum of the potential differences of the accumulators connected in series.



Battery.
Above: series grouping.
Below: parallel grouping.

Galvanometer. Wind an insulated wire into a flat coil of several turns of wire, and mount it vertically with its plane parallel to the magnetic north-south direction, then a small magnetic needle pivoted at its centre will tend to place itself in the plane of the coil. If now an electric current is passed through the coil, the current in the coil will tend to deflect the magnetic needle and make it place itself perpendicular to the plane of the coil, therefore the magnetic actions of the earth's field and of the current act at right angles to each other, and the needle will be deflected through a given angle from its original position in the



A galvanometer.

plane of the coil. The greater the intensity of the current in the coil the greater its action on the needle, and the greater the angle through which it is deflected, since the action of the earth's magnetic field remains constant. Therefore we have here an instrument for measuring the intensity of the electric current, by the angle of deflection of the needle. Naturally the greater the number of turns in the coil the greater the magnetic field due to the current, and the greater the sensitivity of the measuring instrument. Such an instrument measuring the intensity of a current is called a galvanometer.

Mechanical Force on a Current by a Magnetic Field. According to Newton's universal law that any action is balanced by an equal reaction in the opposite direction, it is to be expected that if an electric current acts on the poles of a magnet, reciprocally the poles of a magnet act on an electric current. This was in fact pointed out by Ampére one year after Oersted's discovery of the first effect.

If an insulated wire in which flows a current, is so suspended that it is free to move, and a bar magnet held in the hand is brought near it you will see that the wire will tend to move in a particular direction.

The direction in which the wire tends to move is such that for a swimmer moving along the wire in the direction of the current and facing the north pole of the fixed magnet, the mechanical force on the wire is to his right. This is therefore precisely the force of reaction mentioned above.

The force acting upon the wire depends on the strength of the magnet, and also on the strength of the current in the wire.

This discovery is of very great importance because it provides a very convenient method of getting mechanical work done by means of a current, by making the current flow in the presence of strong electromagnets. In fact this is the principle of the electric motor.

The Electric Motor. A wire wound in the shape of a flat

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rectangular coil is mounted on a horizontal axle, and placed between the two poles of a strong magnet or electromagnet of the horse-shoe type, the axle of the coil being perpendicular to the lines of magnetic force going from the north to the south pole of the magnet. An electric current flows in the coil *ABCD* as shown in the diagram. When the coil is in the position as shown, then applying the above rule, the portion *CD* is acted upon by a downward force, and the portion *AB* by an upward force, the two acting as a couple will make the coil and its axle turn in a clockwise direction, until it arrives at the vertical position. Due to its inertia, especially if there is a heavy fly-wheel fixed on the

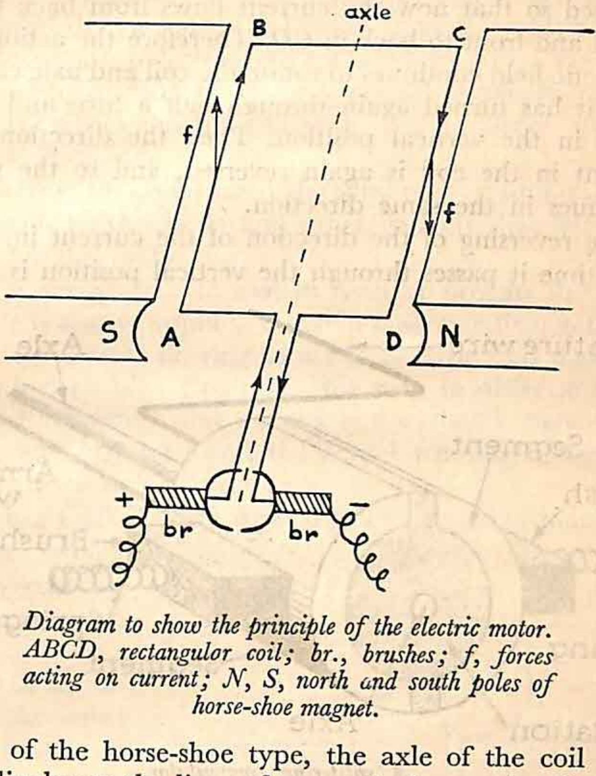

Diagram to show the principle of the electric motor. ABCD, rectangulor coil; br., brushes; f, forces acting on current; N, S, north and south poles of horse-shoe magnet.

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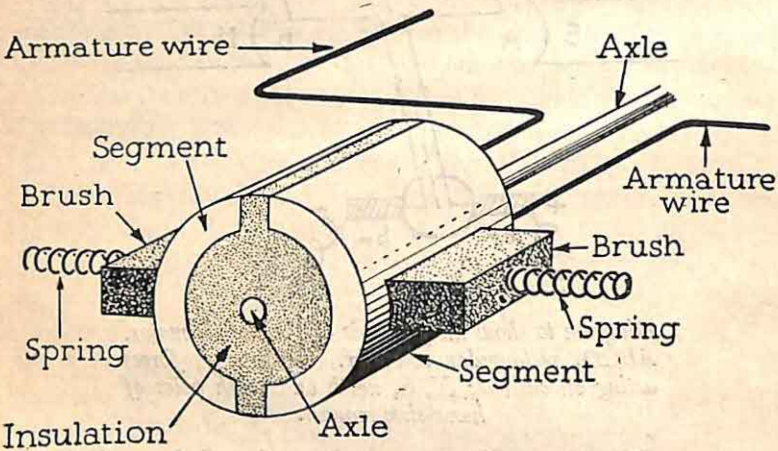
axle, the coil will turn beyond the vertical position, and at the same time the direction of the current in the coil is reversed so that now the current flows from back to front in *BA* and front to back in *CD*. Therefore the action of the magnetic field continues to rotate the coil and axle clockwise until it has turned again through half a turn and is once again in the vertical position. Then the direction of the current in the coil is again reversed, and so the rotation continues in the same direction.

The reversing of the direction of the current in the coil each time it passes through the vertical position is realised by what is known as the 'split-ring' commutator. One end of each of the two rods leading to the coil is connected to one-half of a ring split into two halves, the line of separation being perpendicular to the plane of the coil. Against these two half-rings press two carbon brushes connected to the positive and negative poles of the battery, or any other source of electric supply. From the diagram it is seen that whenever the coil passes through the vertical position, each



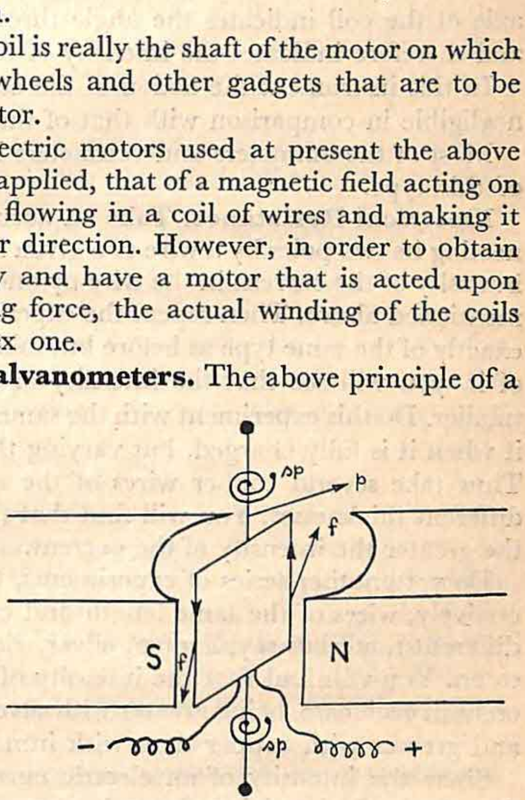
A 'split-ring' commutator.

half of the split ring passes from one brush to the other and so the direction of the current in the coil is reversed. Or better, this arrangement of the split ring makes sure that the direction of the current in the parts of the coil nearer to the north and south pole respectively remains always the same, so that the direction of the mechanical forces on them is always the same and the coil with its axle always turns in the same direction.

The axle of the coil is really the shaft of the motor on which are mounted the wheels and other gadgets that are to be turned by the motor.

In the actual electric motors used at present the above principle is always applied, that of a magnetic field acting on an electric current flowing in a coil of wires and making it turn in a particular direction. However, in order to obtain a greater efficiency and have a motor that is acted upon by a steady turning force, the actual winding of the coils is rather a complex one.

Moving Coil Galvanometers. The above principle of a coil in which flows a current, rotating between the poles of a magnet is applied in the most common type of electrical measuring instruments. In this case also a flat coil of wires is mounted about an axle perpendicular to the poles of the horse-shoe



A moving coil galvanometer.
N.S., north and south poles of magnet; f, forces acting on coil; p, pointer; sp., spiral springs.

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magnet, and the electric current to be measured is passed through the coil. The action of the magnet tends to turn the coil about its axis, but this is partly opposed by two spiral springs one at each end of the axle; the greater the intensity of the current the greater the turning couple acting on the coil, and therefore the greater the angle through which the coil actually turns. A pointer fixed at right angles to the axle of the coil indicates the angle through which it turns and therefore indicates the intensity of the current.

In this instrument the action of the earth's magnetism is negligible in comparison with that of the powerful magnet.

Most of the ammeters and voltmeters in common use are of this type.

Electrical Resistance. Take an accumulator and, connecting its two poles by a wire of a given length, measure the intensity of the current in the wire by one of the instruments mentioned above. Then repeat the experiment taking a wire exactly of the same type as before but taking a greater length of it, you will see that the intensity of the current is now smaller. Do this experiment with the same accumulator using it when it is fully charged, but varying the connecting wire. Thus take several copper wires of the same length but of different thicknesses. You will find that the thicker the wire the greater the intensity of the current.

Do yet another series of experiments, this time using successively, wires of the same length and cross section, but of different materials say, copper, silver, zinc, iron, alloys and so on. You will find that the intensity of the current is different in each case, being greater with silver than with copper, and greater with copper than with iron and so on.

Since the intensity of an electric current corresponds to the flow of electricity through the wire, these various experiments show that various materials, various cross-sections and lengths, oppose the flow of current and offer resistance to the current in varying degrees. This again is very similar to the flow of a liquid through a pipe: the longer, or the narrower, the pipe, the greater the resistance to the flow; the nature of the material of the pipe also matters, because if the inner side of the pipe is smooth and highly polished the flow will be greater. To express the electrical resistance of a conductor by a definite quantity, scientists say that the resistance of a wire is one ohm, if unit intensity of electric current flows through it when the potential difference between its ends is 1 volt. We shall a little further explain that the ampere is the practical unit of intensity of current.

In general, if the intensity of the current is represented by the symbol i, that of the potential difference (=voltage) by v and that of the resistance by r, we have $r=\frac{v}{i}$ or $i=\frac{v}{r}$ or $v=ir$, using the respective practical units of ampere, volt and ohm.

Thus if, in a given wire connecting the two poles of a battery, the intensity of the current is 4 amperes and the potential difference between the two poles is 2 volts, then the resistance of the wire is $\frac{2}{4}=0{\cdot}5$ ohm.

As the above experiments have shown, the electrical resistance of a conductor depends on its length, on its cross-section and on the nature of the substance of which the wire is made.

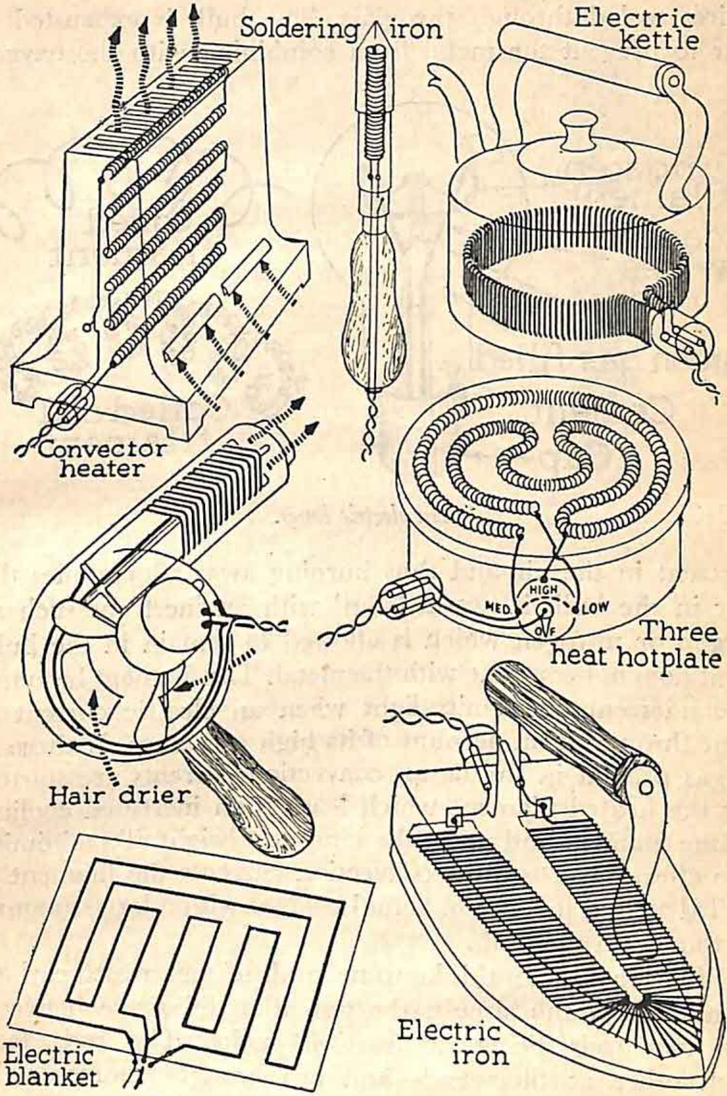
Heating Effects of an Electric Current. This is one of the most obvious and common effects of an electric current. You have only to look at an electric bulb of which the filament is white-hot, due to the current passing through it.

Once again a quantitative relation has been established between the heat given out by a wire and the intensity of the current and the resistance of a wire: a given length of wire having a resistance of r ohms, in which flows a current of i amperes will in unit time (a second) give off heat equal to i^2r joules. Since it takes 4·18 joules to raise the temperature of one gram of water by one degree centigrade (4·18 joules=1 calorie), the heat given out is $\frac{i^2r}{4\cdot 18}$ calories. Naturally since $r=\frac{v}{i}$, v being the potential difference between the two ends of the wire, when a current of i amperes flows in it, the heat given off is $i^2r=\frac{i^2v}{i}=iv$ joules per second. The amount of energy produced per unit time, is called by scientists the power, and in the case of the above practical units 1 joule per second is called 1 watt. Therefore the power of a current of i amperes flowing between two points at a potential difference of v volts is iv watts.

The applications of the heating effect of an electric current are very numerous and of daily occurrence in almost every home, where electricity is available.

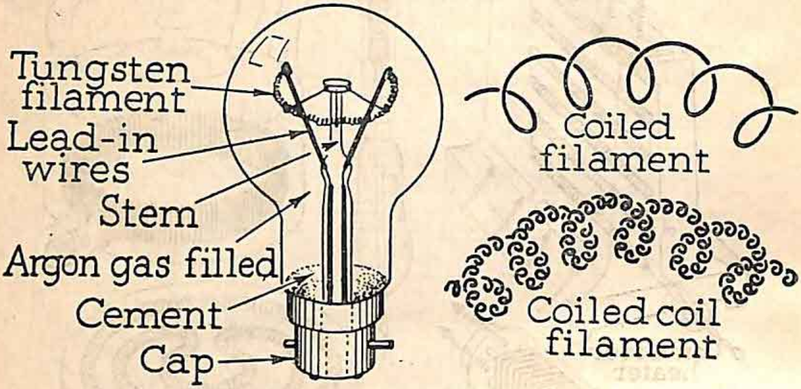
Electrical Heating Appliances. Electric cookers, toasters, irons, kettles, radiators, fires and stoves are appliances which depend on the heating effect of an electric current. All of these contain coils of wires made of certain alloys which offer a high resistance to the passage of an electric current through them. Thus, when an electric current passes through them they become red-hot. In many of these appliances the insulators used are either porcelain or mica. The alloys used are usually nicrome which contains 60 parts of nickel, 25 parts of iron and 15 parts of chromium, or another called manganin which contains 3 parts of copper, 13 parts of manganese and 4 parts of nickel. These alloys undergo practically no chemical change when heated even for a long time with exposure to air.

Electric Lamp. This consists of a glass bulb from which the air is exhausted. Within the bulb is a coiled coil filament of a metal such as tungsten or tantalum fixed to two platinum



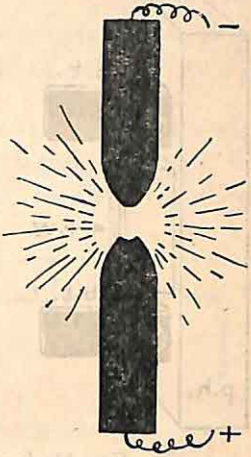
Where are the heating elements in each of these appliances? Why are they placed in these positions?

wires sealed through the glass. The bulb is exhausted of air to prevent the metal from combining with the oxygen present in the air and thus burning away. Sometimes the air in the bulb is 'washed out' with an inert gas such as argon or nitrogen which is allowed to remain in the bulb as it does not combine with the metal. The filament becomes incandescent and emits light when an electric current is sent through it on account of its high resistance. If there is a gas present in the lamp, convection currents are started by the heated filament which lead to an increased cooling of the filament and make the lamp less bright. To minimise the effects due to these convection currents the filament is coiled so that it is not in actual contact with a large amount of the gas in the bulb.



An electric lamp.

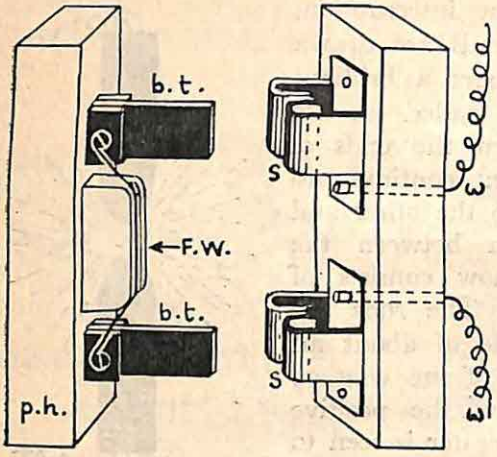
Electric Arc. In this lamp two rods of compressed carbon form part of the circuit, the potential difference between the two rods being at least 40 volts. The rods face each other at their ends and are brought momentarily into contact. When they are in contact the current is switched on. As long as the rods are in contact a strong current flows without interruption, but when the two ends are drawn a few millimetres apart a brilliant flash of white light, called an arc light is seen between the ends of the rods. The current continues to flow from one rod to the other and the conducting path between the ends of the rods now consists of incandescent vapour. The rods are consumed at the rate of about an inch an hour. Most of the wastage occurs at the end of the positive carbon rod where a crater is seen to form while the end of the negative carbon rod becomes pointed. The temperature inside the crater is about 4,000°C. which is about the highest temperature attained by man, with the exception of that obtained in the atomic and hydrogen bombs.



An electric arc light.

The arc light is chiefly used in searchlights and in cinema projectors. In such appliances a concave mirror is mounted behind the negative carbon so as to concentrate the illumination in the forward direction. An electric arc is often used for welding on account of the high temperature produced. This is done by striking the arc between the sheets of metal that are to be welded.

Fuses. If, for any reason, the electric current in a circuit becomes too great there is always the possibility that the copper wires carrying the current would become heated. This may cause the insulation of these wires to catch fire. To prevent such a contingency, a short length of fine wire, called a fuse, is included in the circuit of every electric installation. A fuse is made of an alloy of lead and tin and is usually fixed in an insulator box made of porcelain.



Fuse block connections.
b.t., brass tongues; F.W., fuse wire; p.h., porcelain holder; s, socket; w, wires leading to mains.

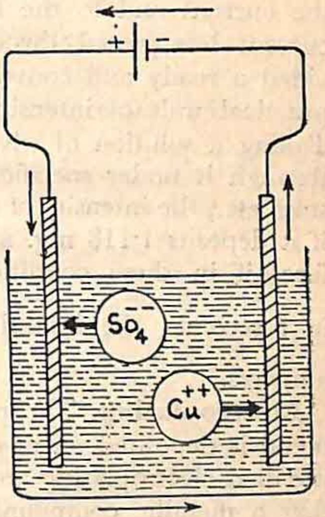
The fuse wire has a much higher resistance than the copper wires carrying the current. Thus when the current exceeds the safety limit the fuse wire gets heated more rapidly than the copper wires, and due to the heat it melts and thus causes the circuit to be broken.

Chemical Effect of an Electric Current. Besides metals, it is found that many solutions are also reasonably good conductors of electricity. Perfectly pure water, without any impurities, will not conduct electricity, but when a small amount of some acid, like sulphuric acid, or of some salt, like copper sulphate, silver nitrate, sodium chloride, etc., is dissolved in water it becomes a fairly good conductor. However, whereas copper or silver wires, through which an electric current passes are not changed or decomposed, but only get heated, in the case of the above solutions, chemical decomposition and recomposition take place in the solution while the current is passing through it.

Electrolysis. We have already mentioned in Book II that when an electric current is passed through a dilute solution of sulphuric acid, the water is decomposed, hydrogen being given off at the negative electrode called the cathode, and oxygen at the positive electrode called the anode.

All substances which in the molten state or when in solution are decomposed by an electric current are called electrolytes, because this decomposition of molecules by an electric current is called electrolysis.

Actually at times a whole series of chemical reactions take place when an electric current is passing through an electrolyte solution. Thus, for example, in the case of a solution of copper sulphate, when the two electrodes dipping in the solution are two copper plates, the copper sulphate molecule $CuSO_4$ breaks up into two electrified particles, called ions, Cu carrying two positive elementary charges represented as Cu^{++} and SO_4 carrying two elementary negative charges represented as SO_4^{--}, the copper ions are naturally attracted by the negative copper electrode, where they give up their two charges and the neutral copper is deposited on the plate, the sulphate ion moves to the positive copper plate where it gives up its two negative charges and then by a process, too complex to be explained here, reacts with the copper of that plate to form a new copper sulphate molecule $CuSO_4$.



Electrolysis of copper sulphate.

In this manner the concentration of the copper sulphate solution is kept constant, while there is a steady transfer of copper from the anode to the cathode. This process would still work if the cathode were a plate of some other metal than copper, or even a rod of carbon.

The same experiment might be repeated with a solution of silver nitrate. In this case silver is deposited at the cathode.

In 1833, an English scientist named Michael Faraday established some very definite and comprehensive rules about the way in which electrolysis takes place.

A point of interest is that when a current passes through an electrolytic solution, the amount of metal deposited at the cathode is directly proportional to the intensity of the current and to the length of time during which the current has passed through the solution. This has provided a ready and convenient way of clearly defining the practical unit of intensity of current called the ampere. Taking a solution of silver nitrate and passing a current through it under specific conditions of temperature, pressure, etc., the intensity of the current is said to be 1 ampere, if it deposits 1·118 mg. at the cathode per second. Therefore, if in these conditions x mg. of silver are deposited in t seconds, the intensity of the current is $i=\frac{x}{1{\cdot}118\times t}$ amperes.

Electroplating. The process by which a thin layer of metal is deposited on any object by the help of electricity is called electroplating and it is the application of the fact that a metallic compound, when either in solution or in the fused state, in the process of electrolysis yields the metal which is deposited on whatever constitutes the negative electrode or cathode.

Articles are electroplated to make them either more beautiful or durable. The article to be electroplated is made the cathode while a block of the pure metal is made the anode. The electrolyte is a metallic compound of the metal used. Thus, if an article is to be plated with copper, the electrolyte is copper sulphate; if it is to be plated with silver the electrolyte is a solution of silver cyanide in potassium cyanide; if it is to be plated with nickel the electrolyte is a solution of nickel ammonium sulphate and ammonium sulphate.

Before an article is placed in the plating bath it is thoroughly cleaned. When a current of electricity is passed through the electrolyte the metal constituting the anode gradually passes into the solution and the article forming the cathode is plated. The electrolyte suffers no loss of concentration during the process but merely helps the transfer of metal from the anode to the cathode. While the article is being plated it is rotated so that its various parts are at the same distance from the anode at suitable intervals. This ensures that the plating is uniform. After it has been plated it is polished.

Electrotyping. This process is similar to electroplating and is used by the printer when he wishes to produce a number of printing plates of type from a single page of type.

A mould of the type is made from either wax or plaster by pressing the page of type into a sheet of wax. The mould is then coated with black-lead so as to conduct electricity. Next, it is connected to the negative of a battery and then suspended in a solution of copper sulphate. A piece of pure copper is connected to the positive of a battery and suspended in the copper sulphate solution. When an electric current flows through the circuit the mould serves as the cathode. After some time the mould becomes plated with a thin layer of copper. It is then removed from the plating bath and the copper shell covering the mould is removed. Finally, molten fusible metal is poured into the side of the shell, which the wax occupied, so as to strengthen the shell.

Polarisation. The simple voltaic cell as described before is unsuitable for general use, as the strength of the current quickly wanes and finally ceases altogether. This weakening of the current is due to a deposition of hydrogen on the copper plate. This effect is known as polarisation.

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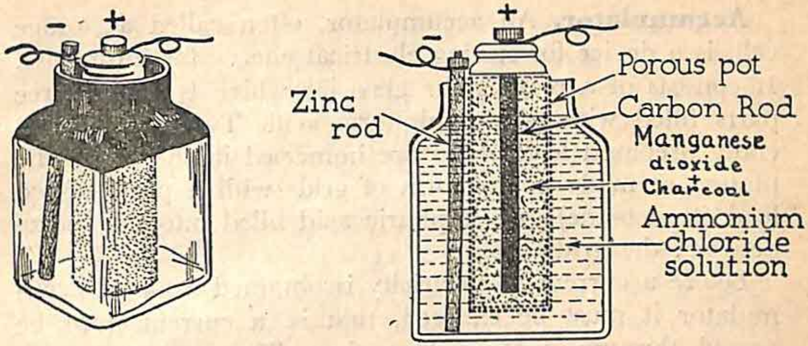
The gas on the copper plate reduces the area of the copper plate which is exposed to the action of the acid. It also provides what may be called a hydrogen plate. Since the current between the zinc and hydrogen plates flows in the opposite direction to the zinc-copper current flowing within the acid in the cell, the result is a gradual weakening of the current.

Polarisation is obviously prevented by getting rid of the obstructing gas. Two kinds of cells have been devised to do this. These cells make use of oxidising agents which supply the oxygen necessary to oxidise the hydrogen to water and thus prevent this gas from collecting on the copper plate.

The Leclanché cell. In this cell, the copper plate of the voltaic cell is replaced by a carbon rod and the dilute sulphuric acid is replaced by a saturated solution of ammonium chloride. The carbon rod is contained in a porous pot and the space between the rod and the inner surface of the pot is closely packed with a mixture of manganese dioxide which is an oxidising agent, and charcoal to increase the surface area of the positive pole and also to absorb some of the hydrogen. The negative pole is an amalgamated zinc plate which is an alloy of zinc and mercury made by rubbing mercury on a clean plate of zinc.

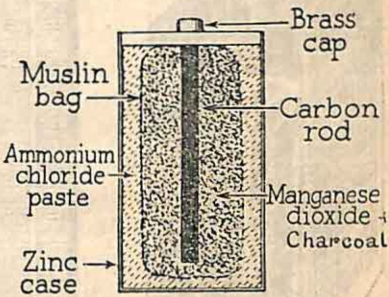
When the positive is connected with the negative through a conductor a current is set up which flows outside the cell from the carbon to the zinc and continues its path inside the cell through the liquid passing from the zinc to the carbon. Bubbles of hydrogen collecting on the carbon rod are oxidised to water by the oxygen from the manganese dioxide. This substance is not a very rapid oxidiser and after a few minutes the hydrogen accumulates and consequently, the current weakens. If the circuit is now broken and the cell allowed to rest, the hydrogen is rapidly oxidised and the cell may be used again. Thus the Leclanché cell



The Leclanché cell.

is ideal for intermittent work such as working an electric bell and for telephones. Zinc is only dissolved by the ammonium chloride solution when the cell is actually working and therefore it lasts for several years before its replacement is necessary.

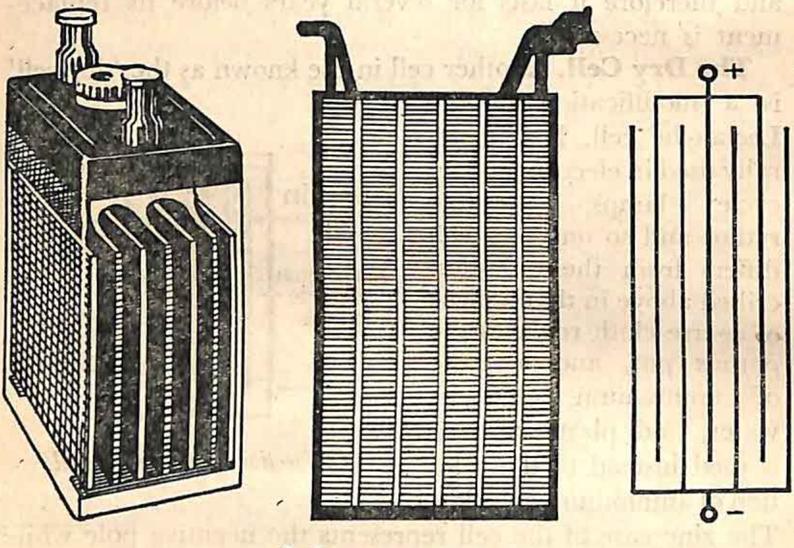
The Dry Cell. Another cell in use known as the 'dry cell' is a modification of the Leclanché cell. It is generally used in electric torches, cycle lamps, portable radios and so on. This cell differs from the one described above in that a piece of coarse cloth replaces the porous pot, and a paste of ammonium chloride, water, and plaster-of-paris is used instead of the solution of ammonium chloride. The zinc case of the cell represents the negative pole while a carbon rod in the middle of the cell represents the positive pole.



Cut section of a unit dry cell.

Accumulator. An accumulator, often called a storage cell, is a device for storing electrical energy for future use. It consists of a rectangular glass jar which is about three parts filled with dilute sulphuric acid. Two sets of specially prepared lead plates are immersed in the acid. The plates are made in the form of grids with a paste of red lead (lead oxide) and sulphuric acid filled into the spaces between the grids.

Before a current of electricity is obtained from an accumulator it must be charged, that is, a current must be passed through it for a long time. The current is sent from a dynamo or from the electric supply mains through the positive plates and out at the negative for about 30 hours. While the current is passing through, a chemical change occurs, in which oxygen and hydrogen are evolved



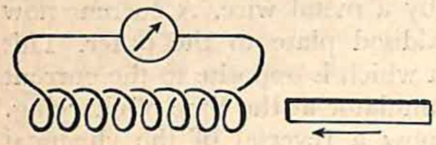
Left: an accumulator.
Centre: a lead accumulator plate.
Right: the arrangement of plates in an accumulator.

by electrolysis. The sulphate ions react with the lead oxide in one set of lead plates at the positive terminal to form an oxide of lead containing still more oxygen called lead peroxide which covers this plate, and which becomes the positive pole of the accumulator. The hydrogen ions react with the lead oxide of the other set of plates (at the negative terminal) to form spongy, metallic lead which covers the second plate, and which becomes the negative pole of the accumulator. After a given period the charging is discontinued, the two plates are joined by a metal wire. A current now passes from the highly oxidised plate to the other. This current flows in a direction which is opposite to the current which passed into the accumulator at the time of charging. This is because there is now a reversal of the chemical action which occurred when the accumulator was being charged. The chemical energy expended during these actions is now converted into electrical energy. During discharge both the metallic lead on the negative plate and the lead peroxide on the positive plate react with the hydrogen produced to form lead sulphate and water. The lead sulphate covers both plates while the water dilutes the acid in the accumulator and thus lowers its specific gravity. The specific gravity of an accumulator is therefore tested periodically by means of a hydrometer and if it is less than 1·2 the accumulator is to be recharged. When the accumulator is being recharged the lead sulphate is reconverted to metallic lead which coats the negative plate and lead peroxide which coats the positive plate, sulphuric acid being produced at the same time so that the specific gravity of the acid in the accumulator increases. Furthermore, hydrogen is set free at the negative plate and oxygen is set free at the positive plate during this reaction. In the sulphuric-acid solution some of the sulphuric acid molecules H_2SO_4 are always split up into two ions: the sulphate ion SO_4^{--} and hydrogen ion H_2^{++}.

Accumulators are chiefly used in motor cars, in electric power stations and in laboratories.

Electromagnetic Induction. Michael Faraday, famous for his laws regarding the chemical action of a current, is still more famous for his discovery in 1831 of a very important phenomenon of electromagnetism.

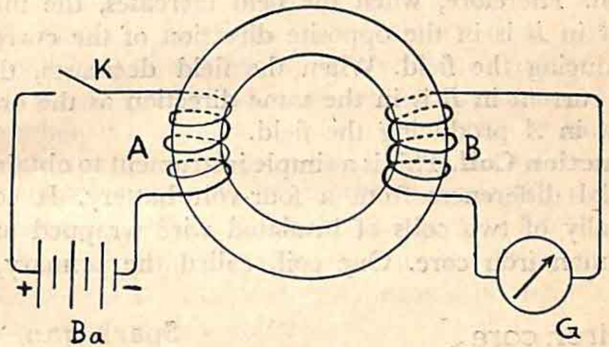
We have seen how a magnet exerts a mechanical force on a wire in which flows a current, the phenomenon we will describe now is just the reverse. Faraday found that if a wire moves towards, or away, from a magnet, an electric current flows in the wire as long as the movement lasts. This means that by moving a conductor, like a wire, across the magnetic lines of force issuing from the magnet, an electric current is induced in the wire, hence the name of electromagnetic induction.



To show electromagnetic induction.

This is conveniently shown by the following experiment. Wind an insulated wire into a coil of a few turns and connect the ends to the terminals of a galvanometer. Take a rather powerful magnet and thrust it quickly through the coil. As you do so the galvanometer needle will be deflected for a short while, showing that a current flows in the coil. If you now quickly pull the magnet back, there is again a deflection, but in the opposite direction, showing that the induced current now flows in the opposite direction. The quicker the magnet is thrust in, or pulled out of the coil, the greater is the intensity of the current produced. Naturally as the magnet is thrust through the coil, the magnetic field through the coil increases, and when the magnet is pulled back, the magnetic field across the coil decreases. Therefore, we see that the increase of magnetic field across the coil induces a current in one direction, and a decrease of the field across the coil induces a current in the opposite direction. We say that a change of the magnetic field across the coil generates an electro-motive force in the coil, which, if it is a closed circuit, results in an electric current.

This was further clearly demonstrated by Faraday when he took an iron ring on which he wound two coils of wire *A* and *B*, the ends of *A* were connected through a key *K* to the terminals of a battery, and the ends of *B* to the terminals of a galvanometer. When the key was closed, the momentary deflection of the galvanometer needle showed that a current was flowing in *B* for a short time, and when the key was again opened, a momentary deflection opposite in direction to the first, showed that a current was flowing in *B* for a short while. The explanation is obvious: on closing the key a current flows in *A* which produces a magnetic field along the axis of the coil and all along the iron ring; therefore, along the axis of the coil *B* a magnetic field is suddenly produced, hence it is an



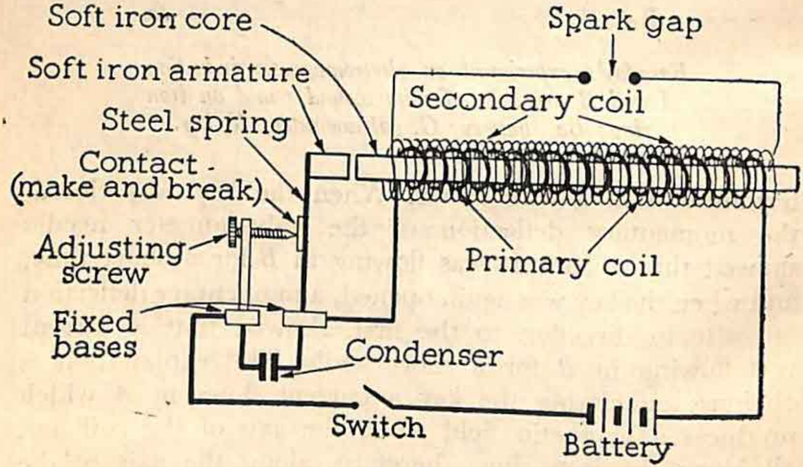
Faraday's experiment on electromagnetic induction. A and B are coils of wire wound round an iron ring; Ba., battery; G, galvanometer; K, key.

induced current. When the key is opened, the magnetic field due to *A* and across *B* is suddenly stopped, hence an induced current in the opposite direction.

It is important to note that the induced current lasts only as long as there is a change in the magnetic field across the coil; further, the more rapid the change of the magnetic field across the coil, the greater the intensity of the induced current.

The direction of the induced current is such as to counteract the increase or decrease of the magnetic field across the coil. Therefore, when the field increases, the induced current in *B* is in the opposite direction of the current in *A* producing the field. When the field decreases, the induced current in *B* is in the same direction as the original current in *A* producing the field.

Induction Coil. This is a simple instrument to obtain high potential differences from a four-volt battery. It consists essentially of two coils of insulated wire wrapped around a common iron core. One coil, called the primary, "con-



The essential parts of an induction coil.

sists of a few turns of thick wire and its ends are joined to the terminals of a 4-volt battery through a make-and-break arrangement similar to that of the electric bell. The other coil, called the secondary, consists of a great number of turns of thin wire, the two ends being connected to two rods terminated by small knobs kept a short distance apart.

As the current in the primary is periodically put on and cut off, the magnetic field across the axis of the coil, also periodically waxes and wanes. This periodic waxing and waning of the magnetic field along the axis of the secondary coil, generates by induction during each turn of the coil, a periodic electro-motive force: in one direction when the magnetic field increases, and in the opposite direction when it decreases. As this coil consists of many turns, this adds up to a high potential difference between the extremities of the coil. Whenever the potential difference is sufficient a spark passes between the two knobs.

Even with a small induction coil, sparks of one inch or more are easily obtained, this means a potential difference of several thousand volts.

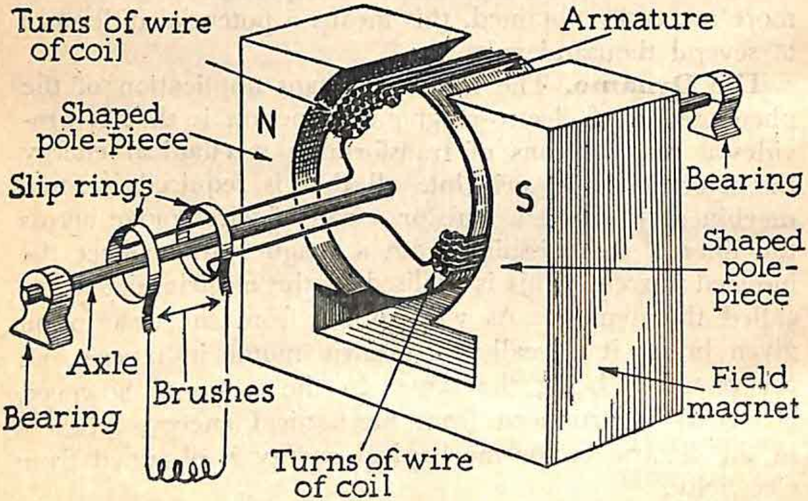
The Dynamo. The most important application of the phenomenon of electro-magnetic induction is that it provides a ready means of transforming mechanical energy into electricity. In principle all that is required is some machinery to make a wire or a coil of wires move across the lines of force issuing from a magnet and collect the induced current. This is realised in the electric generator, called the dynamo. As will appear from the description given below it is really an electric motor in reverse, all the essentials being the same. In the dynamo, however, electricity is produced from mechanical energy, whereas in the electric motor mechanical energy is obtained from electricity.

To explain clearly the working of the dynamo, the illustration shows only a single coil between the poles of a magnet.

The coil is wound around an iron cylinder which constitutes the core. The cylinder is represented in the illustration as a solid structure but it is actually made up of a number of flat sheets of soft iron called 'stampings'. The combination of coil and core is called the armature. The armature is mounted on an axle which rotates continuously in a clockwise direction between the opposite poles of a large horse-shoe magnet. The rotation of the axle is produced by steam or gas engines or by water-power.

The number of coils in the dynamo multiply the strength of the current while the iron core secure an increase in the concentration of the lines of force between the opposite poles. The general arrangement ensures that the lines of force are cut at a very rapid rate and consequently a strong current is produced.

The current produced in the dynamo is collected and



A simple alternator.

led away to an external circuit by means of two slip rings made of copper which are attached to the axis on which the armature rotates (the attachment is not shown in the illustration). One terminal of the coil is soldered to the first slip ring and the other terminal to the second slip ring. As the armature rotates it carries the rings with it. Two brushes, made of copper or carbon are arranged so that they always press against the slip rings.

There are definite rules which enable us to know the direction of the current in each part of the coil as its position changes during the course of its revolution, but these are complications which we will not attempt to discuss here. It is sufficient at this stage to know that the induced current flows in one continuous direction from one end of the coil to the other as the coil moves through half a revolution from one vertical position (perpendicular to the line joining the two poles of the magnet), to the next vertical position; therefore the current passes from one brush through the external circuit and back to the other brush while the coil makes the first half of a complete revolution (0°—180°), until the plane of the coil is again in the vertical position when the current will flow in the opposite direction during the remaining half-revolution (180°—360°). When the coil is in the vertical position it does not cut any lines of force.

Such currents in which the direction of the current is periodically reversed are called alternating currents (A.C.) and the machine producing them is called an alternator. Such a current serves many purposes, yet sometimes another current called a direct current (D.C.) is required in which case a split-ring commutator is used to collect the current so that it always flows in the same direction in the external circuit.

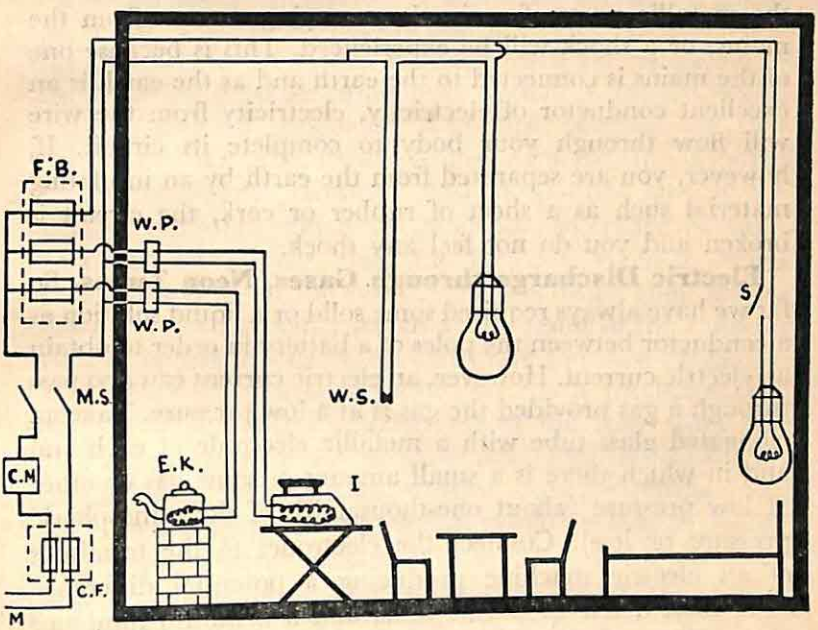
A simple form of commutator is shown in the illustration on page 20. In this arrangement the brushes press against the commutator segments so that at the very moment when the current is changing its direction, that is, when the coil passes through the vertical position, the segment in contact with one brush is brought into contact with the other segment by the rotation of the coil, or in other words, each brush is in contact with each segment of the commutator twice during each revolution. In this way the current is picked up by each brush alternately for every half-period of revolution from the opposite ends of the coil, so that the current in the external circuit always flows in the same direction. The current produced is therefore a direct current, that is, a current which flows continuously in the same direction, and the machine producing such a current is called a direct current dynamo.

Consumption and Cost. An electrical company charges its consumers for the amount of electrical energy they have supplied. You have read that electrical energy is measured in joules. From the above definition it is clear that a joule is the energy expended when 1 coulomb of electricity is moved through a potential difference of 1 volt or when a current of 1 ampere is supplied at a pressure of 1 volt and flows for 1 second. Since this unit of energy is too small to be used for commercial purposes, a multiple of it called a killowatt hour or a Board of Trade unit (B.O.T. unit) is employed. The instrument used for measuring such units is the electric meter.

Since, $1\text{ Volt}\times 1\text{ Ampere}\times 1\text{ Second}=1\text{ Joule}$
or, $1\text{ Watt}\times 1\text{ Second}=1\text{ Joule}$
Therefore, $1000\text{ Watts}\times 3600\text{ Seconds}=36=10^5\text{ Joules}$
or, $1\text{ Killowatt}\times 1\text{ Hour}=36\times 10^5\text{ Joules}$

If a current of 5 amperes under a voltage of 230 volts flows for 3 hours, then the power used is 1150 watts (since, $\text{watts}=\text{amperes}\times\text{volts}=5\times 230=1150$). For 3 hours the energy will be $3\times 1150=3450$ watt hour or 3·45 killowatt hour or B.O.T. unit. At 18·75 P. per unit this would cost a consumer 18·75×3·45=64·7 P.

The Household Supply. Electricity from the electric powe1 station is brought by wires to a place inside the house which serves as a distribution centre. At this place there is a main switch which controls the flow of electricity into the house. From here it is carried to various parts of the house by several pairs of wires, each pair forming a small distribution system called a circuit which provides electricity for only one part of the house. The circuits are wired either in series or in parallel. If the lamps in a house are wired in



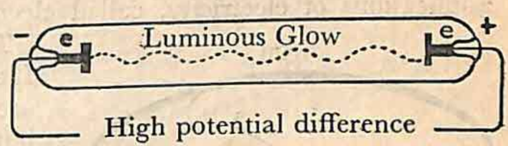
A diagram showing the electrical connections of a room. C.F., company's fuses; C.M., company's meter; E.K., electric kettle; F.B., fuse box; I, electric iron; M, main supply; M.S., main switch; W.P., wall plug; W.S., wall switch; S. switch.

series and the filament of one of them breaks, the electricity can no longer flow through the circuit. To prevent such a contingency the circuits in nearly all our homes are wired in parallel. In such an arrangement only, the electricity required to operate a particular electric device reaches it and therefore it can be switched on or off without affecting the operation of any other device in the circuit.

Wires are always covered with some insulating material such as cotton, rubber or plastic. To prevent such insulation from wearing away, the wires are further protected by a casting of a stronger material.

Care must be taken never to touch an exposed wire or the metallic parts of a circuit conveying current from the mains, or a shock will be experienced. This is because one of the mains is connected to the earth and as the earth is an excellent conductor of electricity, electricity from the wire will flow through your body to complete its circuit. If, however, you are separated from the earth by an insulating material such as a sheet of rubber or cork, the circuit is broken and you do not feel any shock.

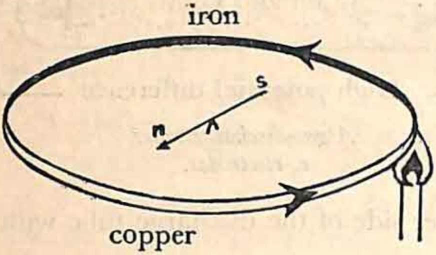
Electric Discharge through Gases, Neon Tubes. So far we have always required some solid or a liquid solution as a conductor between the poles of a battery in order to obtain an electric current. However, an electric current can also pass through a gas provided the gas is at a low pressure. Take an elongated glass tube with a metallic electrode at each end and in which there is a small amount of some gas or other at low pressure (about one-thousandth of the atmospheric pressure or less). Connect the electrodes to the terminals of an electric machine producing a potential difference of at least a few thousand volts, and a beautiful luminous glow will be seen stretching across the tube from one end to the other. According to the pressure of the gas inside the tube the appearance of the glow is different: it may be a continuous streak, or it may be a series of luminous striae separated by short dark streaks. The colour of the glow will also vary with the nature of the gas inside the tube. Thus neon tubes, mercury vapour or sodium vapour tubes will give the characteristic red, green-blue and yellow colours. Other colours can be obtained by coating the inner side of the discharge tube with a fluorescent material.



A gas-discharge tube. e, electrodes.

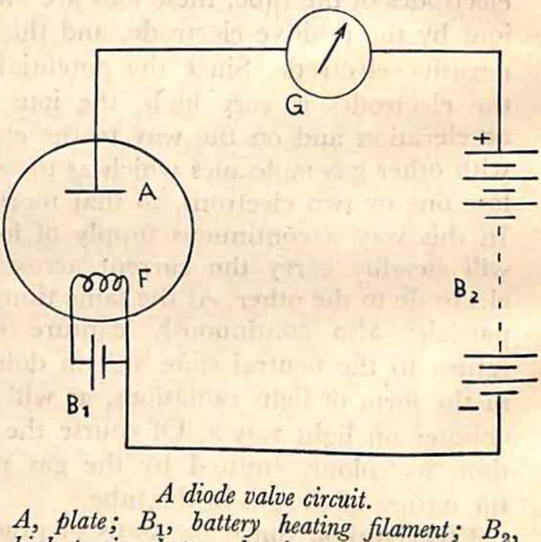
The process of the passage of electricity through a gas at low pressure is different from that of a current through a wire. In the present case at the start there are, as always, a few electrified particles called ions, present in the gas, when a large potential difference is applied between the two electrodes of the tube, these ions are attracted, the negative ions by the positive electrode, and the positive ions by the negative electrode. Since the potential difference between the electrodes is very high, the ions are given a strong acceleration and on the way to the electrodes they collide with other gas molecules which as the result of the collision lose one or two electrons, so that more ions are produced. In this way a continuous supply of ions is produced that will steadily carry the current across the tube from one electrode to the other. At the same time, some of the ionised particles also continuously capture some electrons and return to the neutral state and in doing so release energy in the form of light radiations, as will be explained in the chapter on light waves. Of course the type of light radiation, its colour, emitted by the gas particles depends on the nature of the gas in the tube.

Electronics. Since the basis of practically all electrical phenomena is the electron and the movement of electrons, we should know at least a few other methods of moving electrons or producing electrons on which so much of the recent applications of electricity, called electronics, are based.



Thermo-electric current.
The arrows indicate the direction of the current.

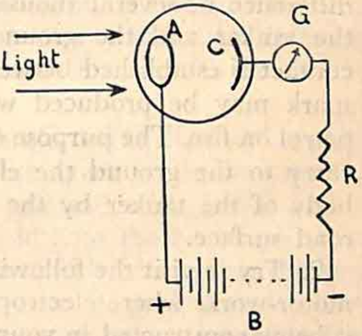
Thermo-electricity. If a copper and iron rod are soldered together at both ends so as to form a closed loop, and one junction is heated while the other is kept cold, a small electric current flows in the loop as shown by the deflection of a magnetic needle pivoted at a point inside the loop. You have here a direct way of transforming heat into electricity. Until now it has not been found possible to obtain intense currents by this method. However, heat produced by 'thermo-couples,' as the above junctions of two different metals are called, is already used in many scientific experiments.



A diode valve circuit.
A, plate; B_1, battery heating filament; B_2, high tension battery keeping the plate A at a positive potential; F, filament; G, galvanometer.

Thermionics. If a tiny coil of wire, inserted in a glass bulb in which there is a vacuum, is heated by sending a current through it, it is found that electrons are being constantly emitted by the heated wire. This can be shown by fixing a small plate a little away from the coil inside the bulb, and connecting the plate through a sensitive galvanometer to the positive pole of a battery. As the filament becomes heated, the electrons it emits are attracted by the plate being at a positive potential, and so a current flows from the filament to the plate, as is shown by the galvanometer. The above arrangement is called a diode thermionic valve or simply a diode valve. We speak of a thermionic current because it is a current produced by ions liberated by heat.

Photo-electricity. Light can also make electrons come out of a metal plate. In a glass bulb in which there is a vacuum, the back surface is covered with a layer of a metal, at some distance from it inside the tube is a metallic ring, the metal and ring are connected to the terminals of a high tension battery, the ring being connected to the positive terminal. When light from a suitable source is directed through the ring on to the metal plate, electrons come out of the plate and are attracted by the ring and so complete the electric circuit and a current flows in it as shown by the galvanometer.



A photo-electric cell circuit. A, ring (anode); B, battery; C, caesium; G, galvanometer; R, resistance.

For most metals the emission of electrons takes place only when ultra-violet light falls on them; however, a few metals like caesium show the effect with visible light. This effect, which has found many applications, is naturally called photo-electricity, since electricity is produced by light.

CHAPTER ACTIVITIES

Outdoors

1. You may have wondered why a chain is allowed to trail on the ground at the back of petrol tankers moving about in the streets of the town. The explanation is based on the production of electricity by friction. Each section of the tyres of the tanker in turn presses for a while against the surface of the road and then moves upwards. In this process electricity is generated and then carried by the tyres upwards where it passes on to the body of the tanker. In this way the tanker gradually gets charged and as it is insulated from the road by the rubber tyres, a potential difference of several thousand volts may develop between the tanker and the ground. If now by chance, a direct contact is established between the tanker and the ground a spark may be produced which may set the inflammable petrol on fire. The purpose of the trailing chain is to steadily carry to the ground the electric charges passed on to the body of the tanker by the tyres after pressing against the road surface.

2. Try to visit the following places (a) a factory such as a motor-works where electroplating is done; (b) a house that is being constructed in your neighbourhood, to see how it is wired for electricity; (c) the electric power station to see how electricity is generated.

For your wall newspaper

Make a drawing of the electric wiring of a few rooms in your house and mount the drawings on your board.

Note-book exercise

Write an essay on 'Electricity in the service of man'.

Laboratory work

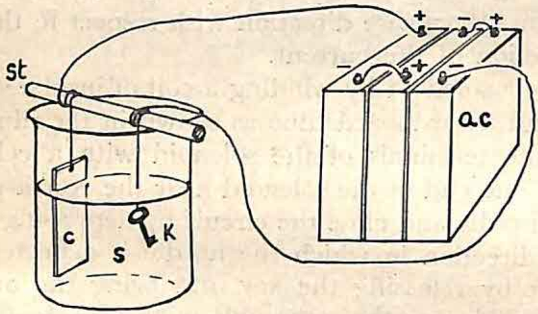
1. Repeat some of the experiments on producing electricity by friction. Get one or two ebonite rods, or plastic rods. As polythene is now being manufactured in India, you will easily be able to obtain rods of that material. These rods, as also the plastic bags used by hosiers, become electrified when rubbed.

2. Punch a hole through the centre of a rectangular piece of cardboard and thread a wire through it. Connect one end of the wire to the positive terminal of an accumulator and the other end of the wire to the negative terminal. Sprinkle iron filings on the cardboard around the wire. Turn on the current and gently tap the cardboard. See how the iron filings outline the circular magnetic field around the wire. By moving a pocket compass around the wire in the same plane as the cardboard it can be seen that with the current flowing downwards, the lines of force are in a clockwise direction with respect to the downward direction of the current.

3. Make a solenoid by winding a coil of insulated copper wire around a cardboard tube as shown in the illustration. Connect the terminals of the solenoid with a cell and a key. Hold one end of the solenoid near the North pole of a magnetic needle and close the circuit by depressing the key. Note the direction in which the needle is deflected. Open the circuit by releasing the key and bring the other end of the solenoid near the same pole of the magnetic needle. Close the circuit again and note the direction in which the needle is deflected. Repeat the experiment with the South pole of the needle. You will find that the solenoid when carrying a current behaves just like a bar magnet for one end of it repels the North pole showing that it is a North pole while the other end of it repels the South pole showing that it is a South pole. Arrange the solenoid in an east-west position and plot the lines of force of the solenoid by means

of a pocket compass. You will find that when the North pole of the solenoid is pointed towards you then the current is flowing in an anti-clockwise direction. Keep the solenoid in the same position, bring a magnetic needle level with it and then close the circuit. Alter the distance of the solenoid from the needle so that the needle shows a very small deflection. Next thrust a bar of soft iron into the solenoid. Note that this causes a great increase in the deflection of the needle. This is because the soft iron core greatly strengthens the magnetic effect of the solenoid. When a solenoid carrying a current has a core of soft iron it becomes an electromagnet.

4. Make a solution of copper sulphate in water, filter it and pour it into a large glass vessel. Take a plate of copper and connect it by wires to the positive terminal of a 4-volt accumulator. Take a key, clean it with emery paper and connect it by wires to the negative terminal of the accumulator. Immerse both the copper plate and key in the copper sulphate solution. The copper plate now acts as an anode while the key acts as a cathode. Allow the



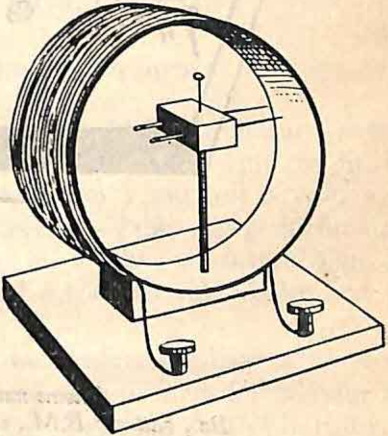
Copper plating.
ac., accumulator; c, copper strip; k, key; s, copper sulphate solution; st., wooden stick.

current from the accumulator to flow through the electrolyte for about half an hour during which time rotate the key in the electrolyte so that it receives an even coating of copper.

At home

1. It is very useful to know how to replace a 'blown' or melted fuse. Before you even touch the fuse-box it is essential that you turn off the main switch. After this has been done, remove the porcelain holder of the blown fuse from the fuse-box. Insert a piece of fuse wire of the same kind and diameter as the melted one into the holder. Replace the holder in the fuse-box and then turn on the main switch.

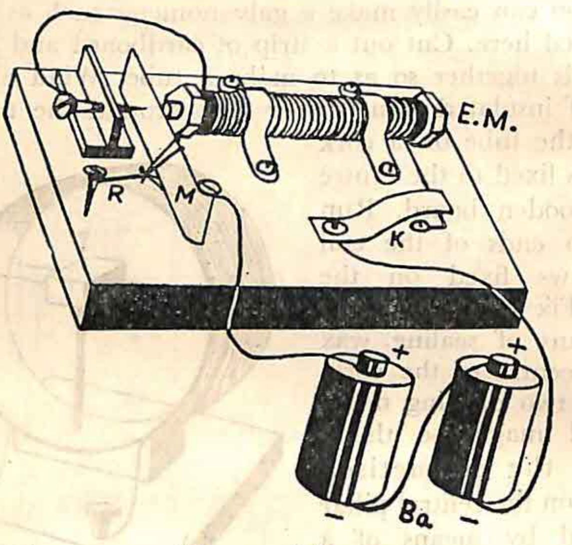
2. You can easily make a galvanometer such as the one illustrated here. Cut out a strip of cardboard and join the two ends together so as to make a tube. Wind about 15 turns of insulated thin copper wire around the tube and mount the tube on a cork which is fixed to the centre of a wooden board. Run the two ends of the coil to screws fixed on the board. Fix a piece of wood by means of sealing wax in the centre of the cork. Obtain two darning needles and magnetise them. Mount the magnetised needles on the central pillar of wood by means of a match-box, a long nail and a bead. Be sure that the like poles of the needles point in the same direction. You will find that



A home-made galvanometer. The bead on which the match-box rests cannot be seen in the picture.

when the plane of the coil is set in the magnetic meridian and an electric current is passed through the coil the magnetic needles are deflected.

3. The accompanying illustration shows how an electric buzzer can be made from materials that are easily available. Note that an insulated copper wire is connected from the positive terminal of a battery to a strip of 'tin' cut out from a tin can. Such a strip is actually made of soft iron and only has a coating of tin. One end of the strip is wrapped firmly around a nail. The strip is held in place by means of a rubber band so that its far end touches the point of another nail. This is mounted on a wooden base so that it is parallel to the base of the buzzer. The electromagnet is simply a



A home-made buzzer.
Ba., battery; E.M., electromagnet; K, key; M, metal strip; R, rubber band.

large soft iron bolt with a coil of insulated thin copper wire wrapped many times around it. Short lengths of adhesive tape at the ends of the bolt prevent the wire from unwinding.

One end of the coil is connected to the contact nail and the other end of the coil is connected to a nail embedded in the base of the buzzer. The electromagnet is held in place by metal strips. The key is a bent strip of metal. One end of the key is fixed to the base by a screw. This end is connected by means of wire to the positive terminal of the battery. When the free end of the key is depressed the circuit is complete and the instrument begins to buzz.

4. Find where the electric meter is kept in your house. Study the rate at which its wheel turns when different electric appliances are being used. Is there any relationship between its speed and the wattage rating on the appliance being used? Ask the man who is employed by the electric supply company to read your meter, to tell you how the charge for the electricity you consume is made.

5. Examine an electric lamp and note that it is marked with both wattage and the voltage of the supply mains on which it is designed to be used. Use these figures to calculate the current taken by the lamp. If, for example, the lamp is marked 230 V-75W then,

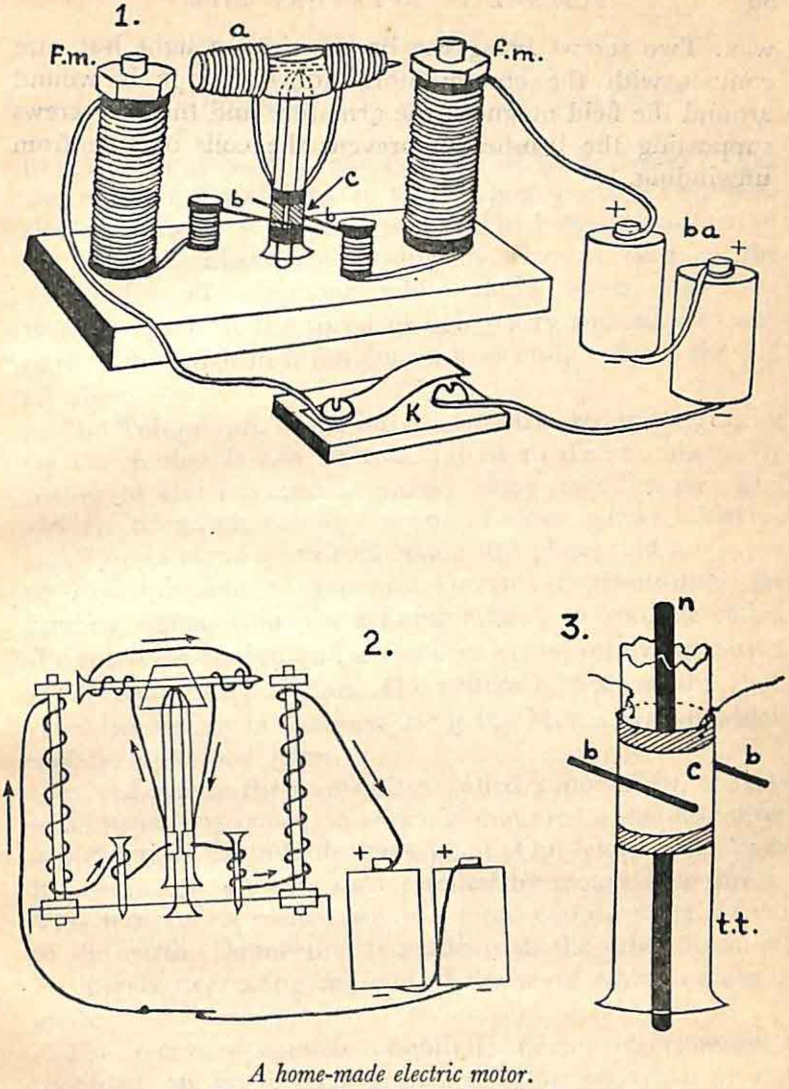
$$\text{Amperes} = \frac{\text{Watts}}{\text{Vo}} = \frac{75}{230} = 0{\cdot}33 \text{ Amperes}$$

A lamp designed to be used on a 230 volt circuit will be marked 230V. If this lamp is used on a 110 volt circuit, it gives out less light than it would on a 230 volt circuit, but lasts for a long time. If, however, a lamp designed for use on a 110 volt circuit is used on a 230 volt circuit it gives out more light than it would on a 110 volt circuit but is soon burnt out.

6. Note the wattage on the electric appliances in your home and find the cost of using each of them for an hour at the rate you pay for electricity. Thus, the cost of burning a 75 watt lamp for 5 hours, when the cost of electricity is 18·75 P per unit, would be:

$$\begin{aligned}\text{Electricity used} &= \frac{\text{Watts} \times \text{Hours}}{1000}\\ &= \frac{75 \times 5}{1000}\\ &= \frac{375}{1000}\\ &= \cdot 375\\ &= \cdot 375 \times 18{\cdot}75\\ &= 7\ \text{P.}\end{aligned}$$

7. In the accompanying illustration of a home-made electric motor the field magnets are two soft iron bolts fitted at either end of a cigar-box. About 75 turns of insulated copper wire were wound around each bolt. When winding, great care must be taken to strictly follow the plan as shown in the sectional illustration. The end of the coil of one field magnet is connected by way of a key to the positive terminal of a battery, while the end of the coil of the other field magnet is connected to the negative terminal of the battery. The insulation is scraped off the free ends of these coils. They now serve as brushes. The commutator is made up of two rectangular strips of sheet copper bent around the open end of a test-tube and bound firmly to it with adhesive tape. There should be a space of about 5 mm. between the ends of the copper strips. The test-tube rests on a nail driven through the centre of the box. The armature is a nail which is driven in through a cork. A single piece of insulated copper wire is bound around the ends of the nail which protrude through the cork. The insulation is scraped off the ends of this wire and connected to the commutator as shown. A hole is made at the lower surface of the cork so as to enable the closed end of the test-tube to fit into it. The cork is then firmly fixed to the test-tube with sealing



A home-made electric motor.
1. *The motor.* 2. *Wiring plan.* 3. *Rotor.*
a, armature; b, brushes; ba., battery; c, commutator; f.m., field magnet; k, key; n, nail; t.t., test-tube.

wax. Two screws bring the brushes into a light but sure contact with the commutator. Adhesive tape is wound around the field magnets, the armature and the two screws supporting the brushes to prevent the coils of wire from unwinding.

CHAPTER II

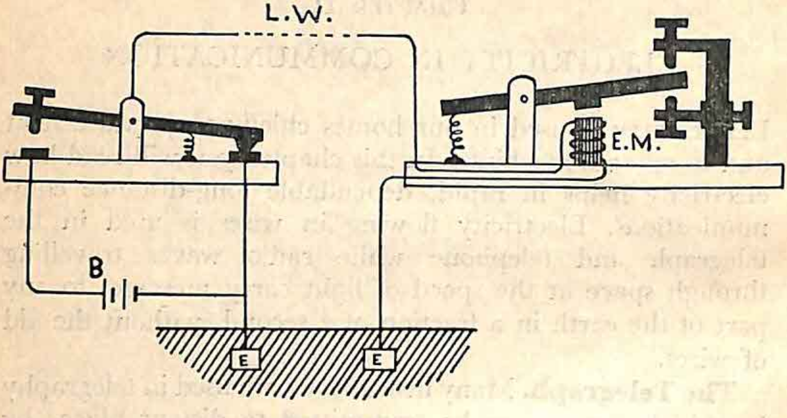
ELECTRICITY IN COMMUNICATION

ELECTRICITY is used in our homes chiefly to produce heat and to operate machines. In this chapter you will read how electricity helps in rapid, dependable long-distance communications. Electricity flowing in wires is used in the telegraph and telephone while radio waves travelling through space at the speed of light carry messages to any part of the earth in a fraction of a second, without the aid of wires.

The Telegraph. Many instruments are used in telegraphy by which signals can be transmitted to distant places by means of electric current passed along metal wires. The electric telegraph chiefly consists of three parts: a circuit made up of metal wires connecting two plates and a battery or its equivalent to generate current; a transmitter for sending signals from the sending station to another called the receiving station and a recorder at the receiving station for receiving such signals. The system of transmitting and receiving signals in common use is the Morse System which will be described here.

In this system the transmitter, called a morse key, consists of an insulating board on which is mounted a metallic lever supported in the middle on a pivot. One end of the lever is kept in contact with one terminal by means of a spring. This terminal is connected to a large copper plate buried in the earth. Connection is made with the other terminal by merely depressing the end of the lever which carries a knob.

The recorder consists essentially of an electromagnet mounted on an insulating board. One terminal of the electromagnet is connected with a large copper plate buried in the earth while the other is connected with the line wires.



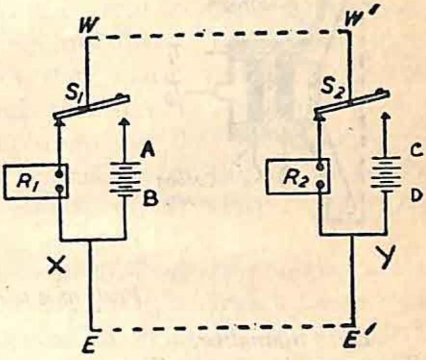
Telegraph instruments.
Left: key. Right: sounder.
B, battery; E, earth; E.M., electromagnet; LW., line wire.

Above the electromagnet is an armature which, although in close proximity of the electromagnet, is kept out of actual contact with it by means of a spring.

When the key at the sending station is depressed, the circuit is complete and the current flows around the coils of the electromagnet at the receiving station. At once the armature is pulled down and as its free end strikes the lower screw, a click is heard. When after a short or long interval the key is released and the circuit is broken, the electromagnet consequently loses its power and the armature is pulled away from the electromagnet by the spring. As its free end strikes the upper screw another distinct click is heard. The operator at the receiving end notes whether the interval between the two clicks is short or long. According to the morse code a short interval corresponds to a dot and a long interval to a dash. Various combination of dots and dashes correspond to the various letters of the alphabet.

At both the sending and the receiving stations there is a key, a recorder and a battery. The stations are connected to each other by a line wire WW', the return path being by way of plates buried in the earth and the earth EE'.

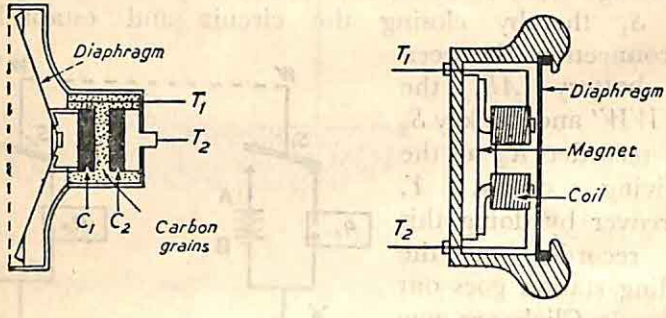
When a man is preparing to receive a message he keeps the back of the end lever in contact with the recorder so that it is disconnected from the battery. When a man sends a message from X as in the illustration, he depresses his key S_1 thereby closing the circuit and establishing a connection between the battery AB, the line WW' and the key S_2 and recorder R_2 at the receiving station Y. Moreover by doing this the recorder at the sending station goes out of circuit. Clicks are now heard in the recorder at the receiving station, the interval between each click depending on the duration of the depression of the key at the sending station.



A telegraph circuit.
AB and CD, batteries; EE', earth connections; R_1R_2, recorders; $S_1 S_2$, switches; WW', line wire; X Y, telegraph stations.

The Telephone. The sound of the human voice can be reproduced over long distances by means of the telephone. This instrument consists of a transmitter or sending apparatus which changes sounds into electric impulses at one end of the line wires which carry the electric currents, and a receiver at the other end of the line wires which change the electric impulses back to sounds.

The chief part of the transmitter is a small insulated box loosely packed with small particles of carbon through which a current of electricity flows when the telephone is being used. On one side of this box is a thin flexible diaphragm made of aluminium. When we speak into the transmitter the resulting air vibrations strike the diaphragm and make it vibrate with the same frequencies as those of the sounds uttered by the speaker. This disturbs the arrangement of the carbon particles by producing a varying pressure on them: a large vibration producing a greater pressure than a smaller vibration. As the particles are pushed close together, due to the increased pressure, their electrical resistance decreases and consequently, more electricity flows in the circuit, whereas when the pressure on them decreases their electrical resistance increases and so less electricity flows in the circuit. In this way the vibrations of the diaphragm bring about variations in the amount of electricity flowing through the circuit which, so to speak, keep step with the movement of the particles. The variations in the amount of electricity flowing through the carbon particles in the transmitter bring about corresponding variations in the amount of electricity flowing through the



Parts of a telephone.

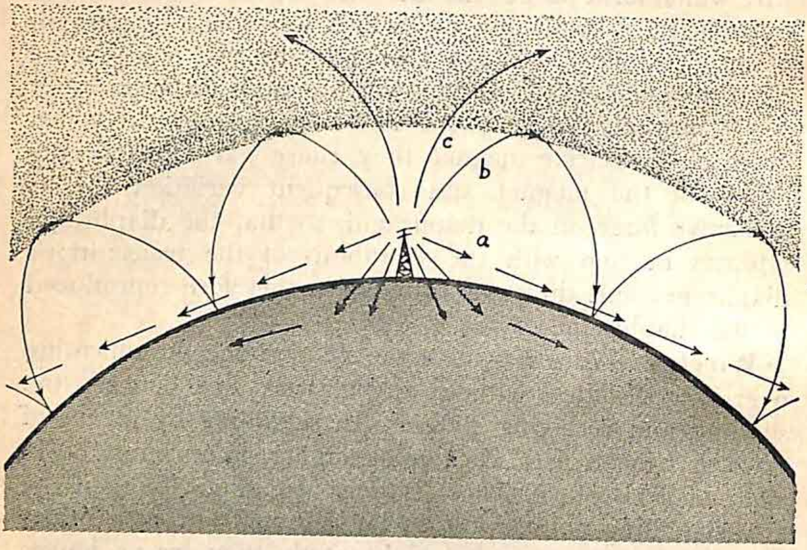
Left: transmitter.
The terminals, T_1 and T_2 are connected to carbon blocks C_1 and C_2 respectively.

Right: receiver.
T_1 and T_2, terminals.

entire circuit. These variations are carried by the line wire to the receiver.

The chief part of the receiver is an electromagnet of the horse-shoe type upon which are wound many turns of wire which form part of the line wire in connection with the transmitter. A small iron disc which serves as a diaphragm is supported near, but not touching, the two poles of the electromagnet. As the varying current from the transmitter passes through the line wires and then through the coiled wires of the electromagnet they cause variations in the power of the magnet and consequent variations in its attractive force on the diaphragm, so that the diaphragm vibrates in step with the vibrations of the transmitter's diaphragm and the same sounds are therefore reproduced at the diaphragm.

Wireless. We now come to the methods of communicating over long distances without any material link between the sending and receiving stations. In signalling by means of flags or beacon fires the two signalling points must be in sight of each other. These systems would not work if the two signalling points were so far distant from each other, that due to the curvature of the earth, they are no longer within view of each other. Unless of course the light signal starting from one point would gradually bend around the earth, or unless they were reflected from some mirror-like surface high up in the air; but, as we know, neither of these actually do take place. Fortunately, besides the light waves which have very tiny wave-lengths, there are other electromagnetic waves of longer wave-lengths which either do bend round the earth, or are reflected, or are gradually bent round high up in the atmosphere. Electromagnetic waves of wave-lengths of 1 Km. and above can travel around the earth over quite a long distance, in fact, nearly one-quarter round the earth, whereas waves of wave-lengths of 500 to 200 metres travel for some distance along the earth, but get rapidly attenuated in the process; at the same time these waves, as also those of shorter wave-lengths, when going straight up into the air are either directly reflected or are gradually bent round by some special layers of the

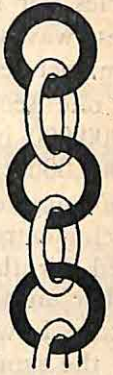


Radio waves.
a, surface waves; b, reflected waves; c, waves going through the ionosphere.

atmosphere at heights between 100 and 250 Km. above the earth. These layers have this special property of reflection or refracting electromagnetic waves downwards because they contain large numbers of electrified particles (ions), hence the name of ionosphere given to this region of the atmosphere. Longer waves, like those of 1 Km. or more, are similarly reflected but at a lower height above the earth. Whereas very tiny waves like those of light go right through the ionosphere without any appreciable reflection or refraction.

Therefore we must now look for a practical way of producing electromagnetic waves of rather long wave-lengths, which could be used to carry messages over long distances from one point of the earth to another.

Production of Electromagnetic Waves. You have read and found by experiment that an electric current flowing in a wire produces a magnetic force all around it. This force varies with the intensity of the current and its direction depends on the direction of flow of the current. If therefore an alternating current flows in the wire, the magnetic field all around it will periodically be reversed in direction, and the strength of the force will also periodically vary from a maximum in one direction, then gradually to zero, then again increasing in the opposite direction. Now according to the principle of electromagnetic induction, if the magnetic force varies in the space around the wire, this variation will produce an induced electric force. This varying electric force will in turn produce a varying magnetic force and so we see that when an alternating electric current flows in the circuit it will set up all around it a set of periodic electric and magnetic disturbances gradually spreading out in all directions, this is what we call electromagnetic waves. We may compare this to a set of links in a chain, each alternate link representing the varying magnetic forces, the other set of alternate links representing the varying electric forces. Of course, in reality, there are no such material links, but only electric and magnetic forces interlinking and gradually spreading out into space all around the original oscillating current. It was James Maxwell, an English physicist who in



Illustrating the nature of electromagnetic waves. Black rings: electric fields. White rings: magnetic fields.

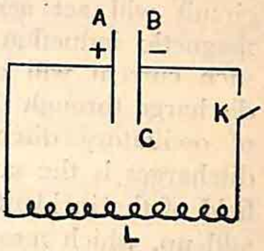
1865 gave the mathematical theory of this propagation of electromagnetic waves. He showed that they would propagate with a velocity equal to that of light. Some years later, in 1888, a German physicist named Heinrich Hertz verified by actual experiments the theoretical deductions and predictions of Maxwell. The next problem naturally was how to produce a regular set of oscillating electrical currents which would give off a regular set of electromagnetic waves.

Electrical Oscillating Circuits. You might say that we have the town supply of alternating current (A.C.) in our homes, which will provide us with a regular set of electromagnetic waves. Unfortunately this will not do, because the energy propagated by the electromagnetic waves becomes only appreciable if their frequency is at least 100,000 cycles per second, which is very much greater than the 50 or 60 cycles per second of the A.C. of the town supply. Since these waves travel with the velocity of light, that is 300,000 Km. per second, and the number of wave-lengths covered in one second is equal to the frequency, by dividing 1,000,000 into 300,000 Km. we find that a frequency of 1,000,000 c.p.s. corresponds to a wave-length of 300 m.

Fortunately we have a very convenient method of producing extremely rapid oscillating currents, the main gadgets used for this being condensers and coils of wire wound either on an empty cylinder or on an iron cylinder called a core. In what follows we shall always represent a condenser by the symbol C and the coil by the symbol L.

You have seen that when an electric current flows in a solenoid, especially when wound on an iron core, it produces a strong magnetic field inside and around the coil. The strength of the magnetic field is proportional to the intensity of the current and also depends on the number of turns in the coil and on whether there is an iron core or not (the two latter factors are referred to as the inductance of the coil). Therefore in the case of a given coil, the magnetic field will vary with the current flowing in the coil. In particular, if the intensity of the current and therefore the magnetic field decreases gradually, a current will be generated in the coil due to electromagnetic induction and will tend to maintain the flow of current in the original direction.

Consider now the following system consisting of the condenser *C* of which the two plates *A* and *B* are connected by a coil *L* through a key *K*. First we charge the condenser *C* by connecting its two plates to the two terminals of a battery. Supposing *A* is positive and *B* is negative, then as the key *K* is closed, a momentary current flows through the coil *L* from *A* to *B*. But very soon the current decreases as *A* loses its charge, this means that a decreasing current in the coil *L* produces a rapidly decreasing magnetic field and this in turn generates a current flowing in the direction from *A* to *B*. This will result in *B* becoming positive with respect to *A*, and now a current will momentarily flow from *B* to *A* and then the reverse process of what was just explained occurs; so that after a while *A* is again positive with relation to *B*. Therefore, we shall have a series of electric oscillating discharges in this circuit, called an oscillating circuit. Naturally at each discharge a certain amount of energy is dissipated in the form of heat and otherwise, so that gradually the oscillating currents grow weaker and after a few oscillations die out; in a word, we have here a set of damped oscillating currents.



Oscillating circuit.

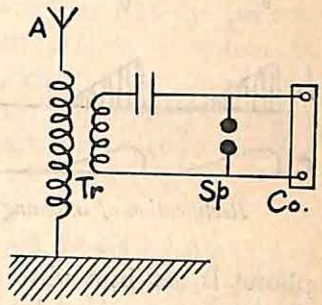
A more detailed study of these phenomena show that the frequency of these oscillatory discharges depends on the capacity of the condenser and on the inductance of the coil:

the smaller either of them are, the greater the frequency. Hence we have here a ready means of producing a periodic oscillating current of any required frequency, and naturally such oscillatory electric currents will send out electromagnetic waves of the same frequency.

How are we to detect the presence of these periodic electromagnetic disturbances propagating in all directions from the oscillatory circuit? Suppose at a certain distance we put up a similar circuit consisting of a condenser *C* connected through a coil *L*, their capacity and inductance being the same as those in the oscillatory circuit. The periodic magnetic disturbances sent out by the oscillatory circuit will act across our new circuit and by electromagnetic induction set up an oscillating current. Each such current will charge the condenser which will then discharge through the coil, this being followed by a series of oscillatory discharges. Since the frequency of these discharges is the same as that of the oscillating magnetic field of the incident wave, the two effects will always just add up, which means that the two are in resonance. Just as the vibrations of a tuning fork will set vibrating another tuning fork of the same frequency, but not a tuning fork of a different frequency, so also in our present case if our receiving circuit is 'tuned' to the same frequency as the emitting circuit, by properly adjusting the capacity and inductance, then an electromagnetic wave emitted by the emitting circuit will set the receiving circuit into resonant oscillation. This explains why you have to tune in your receiving radio set to the particular broadcasting station you want to listen to. It means that noting the particular wave-length, or frequency, on which this station broadcasts, you turn one or more knobs of your receiving set which will adjust the capacity and inductance of its oscillating circuit so that it is of the same frequency as that of the emitting station.

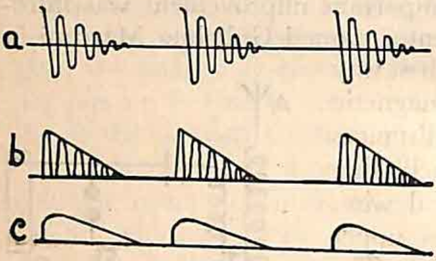
It was by using simple emitting and receiving oscillatory circuits like the above that Hertz proved experimentally the existence and main properties of electromagnetic waves. However, in this way he could send out waves over only short distances.

The Aerial. A very important improvement was introduced by an Italian inventor named Gulielmo Marconi in 1896. He showed that the best way of propagating electromagnetic waves over very long distances was to set up the oscillating currents in a long vertical wire, joined, if possible, at its upper end to a horizontal wire. The same applies to the receiving set. Here also by setting up such a vertical wire, called an antenna or aerial, much stronger oscillating currents are set up by the incoming electromagnetic waves. The aerial itself constitutes the oscillatory circuit or it may be coupled through a transformer to an oscillatory circuit, as shown in the figure.



A, aerial as radiator; Co., induction coil for charging condenser; Sp., sparking gap; at each spark the condenser is discharged; Tr., coupling transformer.

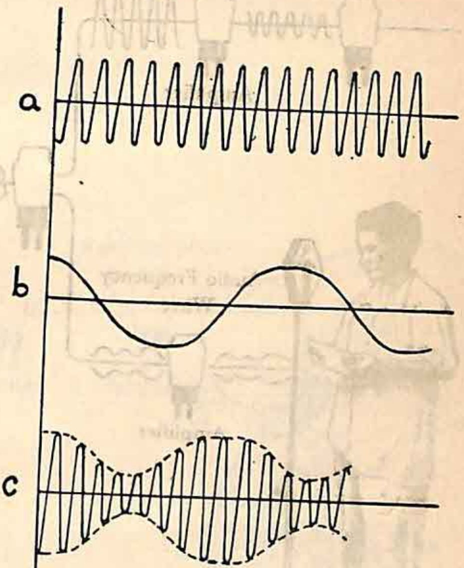
Wireless Telegraphic Communication. With what we have explained so far, we have practically all that is needed to transmit signals according to the Morse Code or any similar code. In the present case it means that for a dot the condenser in the oscillatory circuit at the emitting station will be charged a small number of times, which will result in the emission of a small number of damped wave-lengths; for a dash the condenser will be charged a greater number of times. At the receiving set when the above wave-trains reach it, they will set up a shorter or longer series of damped oscillations, corresponding to the dots and dashes. In the receiving set the oscillating currents are first rectified, which means transformed into direct currents, always flowing in the same direction. This was done at first by special types of crystals, now it is done by triode valves. The result of this rectification is shown in the figure: the successive sets of damped oscillations *a* are transformed into sets of small direct currents *b*, these are then passed on to a telephone.



Rectification of incoming waves.

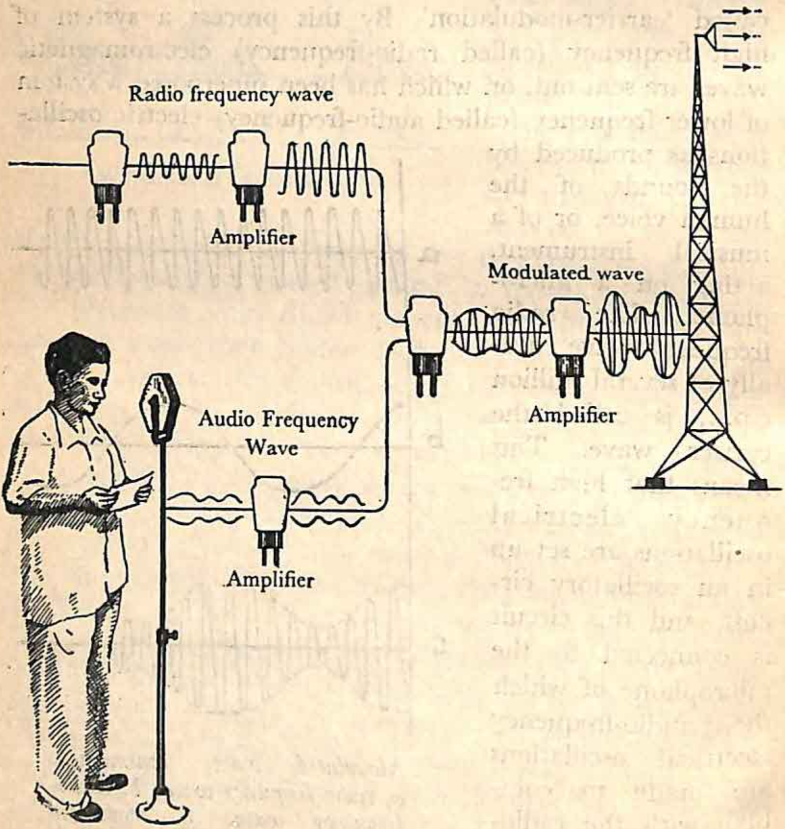
As you have read before, the vibrating diaphragm in the receiver of the telephone is set into vibration by the oscillating currents in the electromagnet placed behind it. In the present case the successive short direct currents corresponding to one damped wave train follow each other so rapidly that all their actions in the electromagnet add up to one: giving one push to the diaphragm as shown in *c*. After this the diaphragm falls back until it receives another push from the following set of rapid direct currents. Therefore, the diaphragm will move with a frequency equal to that of the number of times the condenser is charged at the emitting station. For the telephone to give thus an audible sound, the frequency with which the condenser is charged must therefore be within the audio-frequency, that means a few hundred or more cycles per second. In fact this is done automatically by the special manner in which the oscillating circuit at the emitting station is being charged.

Transmission of Speech and Music. You have read how in the telephone or in the microphone the sound vibrations are transformed into electrical vibrations, of frequency equal to that of the sound, which means a maximum of about 16,000 c.p.s. These electrical oscillations cannot be used directly to transmit electromagnetic waves of the same frequency, because, as we have said before, for an electromagnetic wave to be propagated over a long distance with an appreciable degree of intensity, a frequency of 100,000 c.p.s. is a low minimum. The solution to the problem of transmitting sounds perceptible to the human ear, by means of electromagnetic waves, was found in the process called 'carrier-modulation'. By this process a system of high frequency (called radio-frequency) electromagnetic waves are sent out, on which has been superposed a system of lower frequency (called audio-frequency) electric oscillations as produced by the sounds of the human voice, or of a musical instrument, acting on a microphone. The radio frequency wave, usually of several million c.p.s., is called the carrier-wave. This means that high frequency electrical oscillations are set up in an oscillatory circuit, and this circuit is connected to the microphone of which the audio-frequency electrical oscillations are made to combine with the radio-frequency electrical



Modulated wave transmission. a, radio-frequency wave; b, audio-frequency wave; c, modulated wave: combination of a and b.

oscillations. At times the two electrical vibrations, acting together, add up to give a great maximum of intensity, and a little later, acting in opposite directions, they produce a minimum, and in between the two there are various combinations. The result is still a high-frequency oscillating current, but of which the intensity or amplitude waxes and wanes periodically, with a frequency corresponding to that of the oscillations from the microphone. This is shown in the figure on the preceding page.

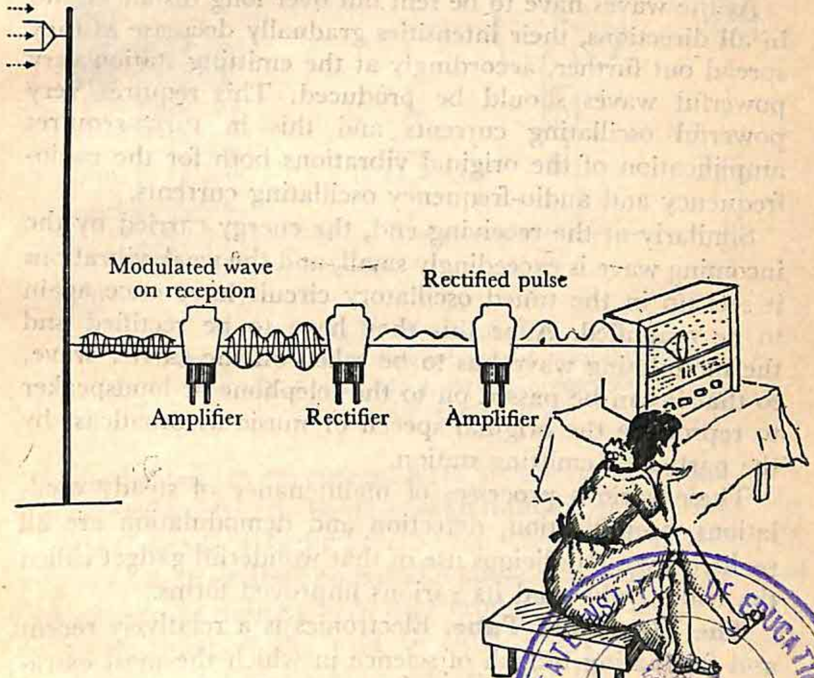


Broadcasting.

This modulated high-frequency oscillating current sends out into space modulated high-frequency electromagnetic waves.

At the receiving end, these modulated high-frequency electromagnetic waves will set up in a properly tuned oscillating circuit an oscillating current of high frequency, but of which the intensity varies periodically with a frequency to that of the modulating agent.

These oscillating currents, being very weak, are first amplified, then rectified, and as explained above, the resultant direct currents over one wave of the audio-frequency will all add up. Therefore, there is acting on the telephone



Listening in.

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or loudspeaker, a periodic set of currents of audio-frequency and therefore reproducing the sound which originally acted on the microphone at the emitting station.

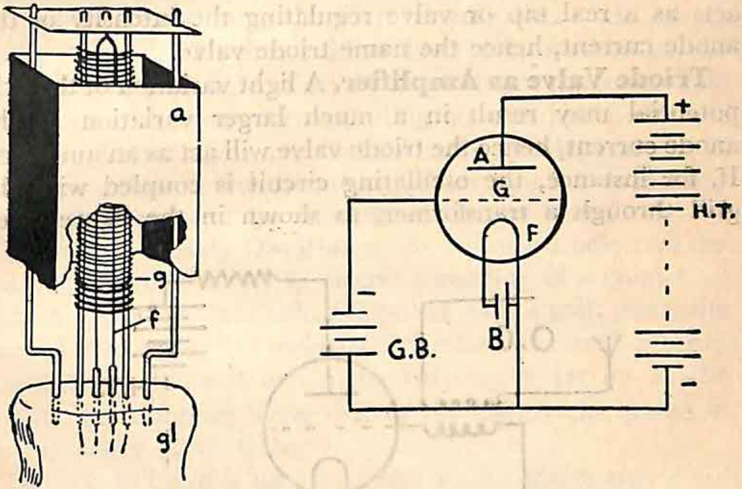
The process just explained implies quite a number of steps of a rather technical nature. First of all we require a continuous carrier-wave of high frequency and of steady intensity or amplitude. Now in the process explained above we could only get a rapid succession of damped electrical oscillations producing therefore a rapid succession of damped electromagnetic waves. We need therefore some arrangement that will keep the oscillating current going on for any length of time and with constant intensity.

As the waves have to be sent out over long distances and in all directions, their intensities gradually decrease as they spread out further, accordingly at the emitting station very powerful waves should be produced. This requires very powerful oscillating currents and this in turn requires amplification of the original vibrations both for the radio-frequency and audio-frequency oscillating currents.

Similarly at the receiving end, the energy carried by the incoming wave is exceedingly small, and the weak vibrations it sets up in the tuned oscillatory circuit have once again to be amplified. After this they have to be rectified and the modulating wave has to be taken off the carrier wave, so that it can be passed on to the telephone or loudspeaker to reproduce the original speech or music as broadcast by the particular emitting station.

These various processes of maintenance of steady oscillations, amplification, detection and demodulation are all realised by the judicious use of that wonderful gadget called the triode valve and its various improved forms.

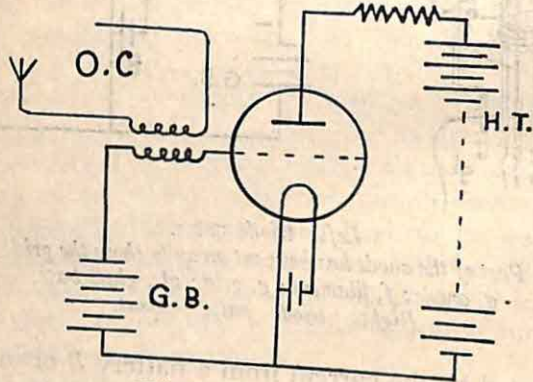
The Electronic Tube. Electronics is a relatively recent and fascinating branch of science in which the most extraordinary tricks are produced by playing with extra-light particles of negative electricity called electrons. The one marvellous application of electronics we consider here is the triode valve. It essentially consists of a glass bulb in which a high vacuum has been produced; it contains a thin metallic filament, surrounded by a wire spiral or a cylinder of gauze called a grid and this is surrounded by a metal cylinder called the anode. It is usually represented schematically as shown in the diagram. The filament *F* being heated by the current from a battery *B* or some other source of electricity, emits a large number of electrons. The plate or anode *A*, being kept by the High Tension battery *H. T.*, at a high positive potential relative to *F*, attracts many of the electrons emitted by *F*, thus producing an anode current. The function of the grid *G*, usually kept at a negative potential relative to *F* by the battery *G.B.* (Grid Bias), regulates the flow of electrons from the filament to the



Left: triode valve.
Part of the anode has been cut away to show the grid.
a, anode; f, filament; g, grid; gl., glass base.
Right: triode valve circuit.

plate. If the grid is negative it will tend to push the electrons back to the filament, but the plate being at a high positive potential will strongly attract the electrons, therefore they may overcome the repelling force of the grid. This naturally depends on the potential of the grid; if it is made less negative, or even slightly positive then there will be a large flow of electrons from the filament through the grid to the plate and so a large anode current will result. The grid therefore acts as a real tap or valve regulating the intensity of the anode current, hence the name triode valve.

Triode Valve as Amplifier. A light variation of the grid potential may result in a much larger variation in the anode current, hence the triode valve will act as an amplifier. If, for instance, the oscillating circuit is coupled with the grid through a transformer, as shown in the figure, then even small varying currents in the oscillating circuit will, by acting on the grid, greatly influence the anode current, and thus result in an amplification of the original oscillating current.

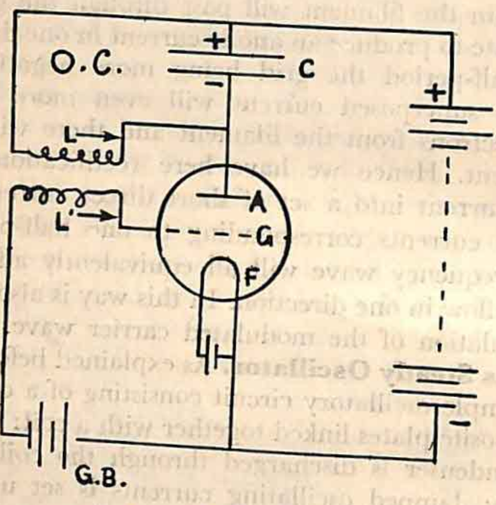


Triode valve as amplifier.

Triode Valve as Detector. If the potential of the grid is so adjusted that it just repels the electrons coming out of the filament by superposing on the grid a varying current, like the one from the oscillating circuit in the receiving set, then for each half-period of the wave when it is positive, electrons from the filament will pass through the grid and go to the plate to produce an anode current in one direction; the next half-period the grid being more negative than without the superposed current will even more strongly repel all electrons from the filament and there will be no anode current. Hence we have here rectification of the oscillating current into a set of short direct currents. The short direct currents corresponding to one half-period of the audio-frequency wave will all equivalently add up to one electric flow in one direction. In this way is also realised the demodulation of the modulated carrier wave.

Triode as Steady Oscillator. As explained before in the case of a simple oscillatory circuit consisting of a condenser with its opposite plates linked together with a coil: when the charged condenser is discharged through the coil a series of gradually damped oscillating currents is set up in the circuit, the damping being due to the energy dissipated in the successive oscillations.

The triode valve is used to make up for the energy dissipated in each oscillation, by communicating each time a fresh charge to the condenser. The triode valve and its accessories are joined to the ordinary oscillatory circuit as shown in the figure on the next page. The lower plate of the condenser *C* of the oscillatory circuit is joined to the plate *A* of the triode, and the upper plate of *C* is joined to the positive terminal of the *H.T.* battery. The grid is coupled with the oscillatory circuit by means of a coil *L'* between the grid bias battery and the grid, this coil *L'* is close to the coil *L* of the oscillatory circuit. Therefore, when a current flows in the *CL* circuit the magnetic field produced in *L* also acts on *L'* and thus induces in it a current by electromagnetic induction. Suppose now that an oscillatory discharge is going on in the *LC* circuit, and at one time the current flows from the upper plate of *C* through *L* to the lower plate,

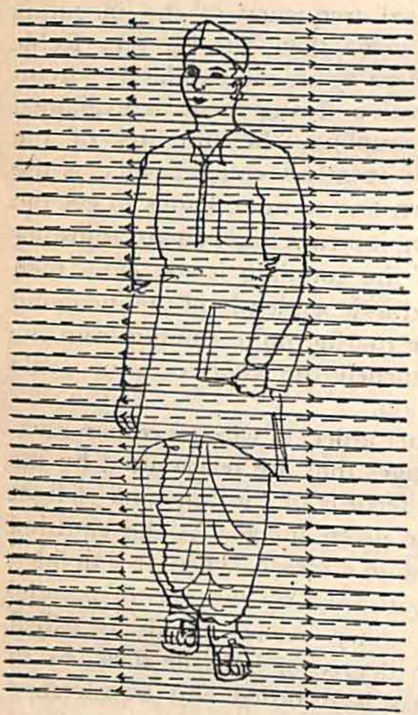


Triode to maintain steady oscillations.

and then gradually decreases. This corresponds to a decrease in the magnetic field in both *L* and *L′* and therefore will induce a current in *L′* flowing in the same direction as the decreasing current in *L*. This means that the grid will be less negative, and therefore more electrons will pass through it and go to the plate *A* and from there to the lower plate of the condenser. This is equivalent to giving an extra charge to the condenser. Similarly, at the next half-period, when the current in *CL* flows in the opposite direction, once again the condenser will be given an extra charge. Therefore the triode valve acts as a booster, maintaining the oscillating current in the oscillatory circuit *CL* in a steady manner for as long as desired. Naturally the degree of coupling between the coils *L* and *L'* will determine the maintenance or even amplification of the oscillating current.

At the receiving end it is the same, the oscillatory circuit is first tuned for the special frequency of the incoming wave that is wanted, this wave then sets up very feeble oscillations in the circuit. Here again the oscillatory circuit is 'coupled' with a triode valve arrangement as explained above, and, by suitable coupling, the intensity of the incoming oscillations can be greatly increased. That is the reason why you have to turn one or more knobs to get the right volume in the reception, it means that you are adjusting the coupling. Of course if the coupling is too close then oscillations will be produced independently of the incoming wave, and this explains the roaring noise coming from the loudspeaker if you have turned the knob of your radio set too much in one direction.

Television. This is another aspect of wireless communication. In this case the messages that are transmitted by the electromagnetic waves are records of the amounts of light in the various areas of the given image. At the emitting station the image is focussed on a screen, where it is divided into a large number of small areas by two sets of parallel lines, one horizontal, the other vertical. This is called 'scanning' the image. The degree of light or darkness in each of the successive areas is recorded and transformed into an electric current of which the intensity is proportional to the intensity of light in each area. The currents of varying intensity are amplified and then superposed on the high-frequency oscillating current in the oscillatory circuit of the emitting set. This results in a modulated high-frequency oscillating current which then sends out similar modulated high-frequency electromagnetic waves. At the receiving end these waves set up modulated high-frequency electric oscillations, which are first amplified and then rectified and detected, so that now we have a succession of currents of different intensities. These are again transformed into light of corresponding intensities, which is used to illumine on a screen small areas in the same order as was followed at the emitting station. In this manner the original picture is reproduced here with the same degrees of light and shade in the various areas. Naturally the whole area of the picture so reproduced must be covered in less than $\frac{1}{25}$th of a second so that to the human eye all the successively illuminated areas appear as one whole. And this whole process must be repeated at the same speed, if the picture is to remain visible for some length of time. In case the picture to be televised is that of a living scene, say a football match, a republic day parade, a coronation of a king or pope, then at the emitting station the original image must be analysed for the varying amounts of light and shade in all the areas into which the image is divided, at a very great speed so that the whole image is covered before an appreciable change in the scene has occurred. Then also at the receiving end the image reproduced will gradually but imperceptibly change, as in the case of a cinema projection arrangement.

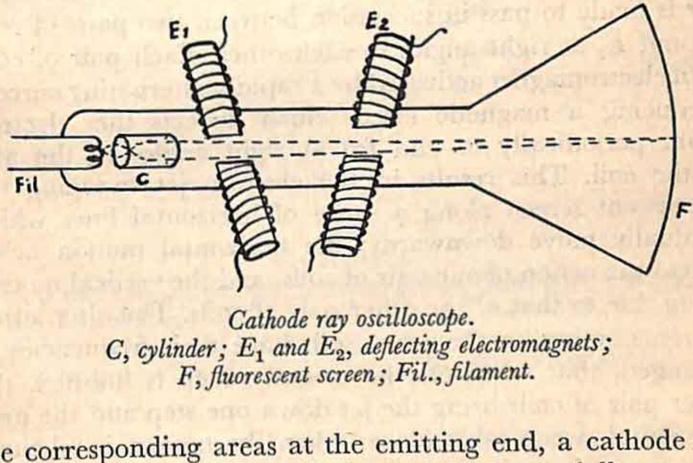


Scanning an image.

The way in which the amounts of light and shade in the numerous small areas of the image are transformed into electric currents of corresponding intensity and the way in which the whole picture at the emitting and receiving end is covered in a fraction of a second, are some more wonderful applications of the science of electronics.

The Photo-electric Cell. As explained in the previous chapter, in the photo-electric cell, a beam of light is transformed into an electric current of which the intensity is proportional to the light intensity. Therefore if the light from the different small areas making up the image is directed in quick succession on a photo-cell, a photo-electric current will be produced of which the intensity will vary in accordance with the amount of light or shade in the successive small areas of the image.

To reproduce the varying intensities of current at the receiving end into corresponding bright patches and to align them in very rapid succession in the same manner as the corresponding areas at the emitting end, a cathode ray oscilloscope is used. A cathode ray tube essentially consists of an elongated tube as shown in the figure. At the broad



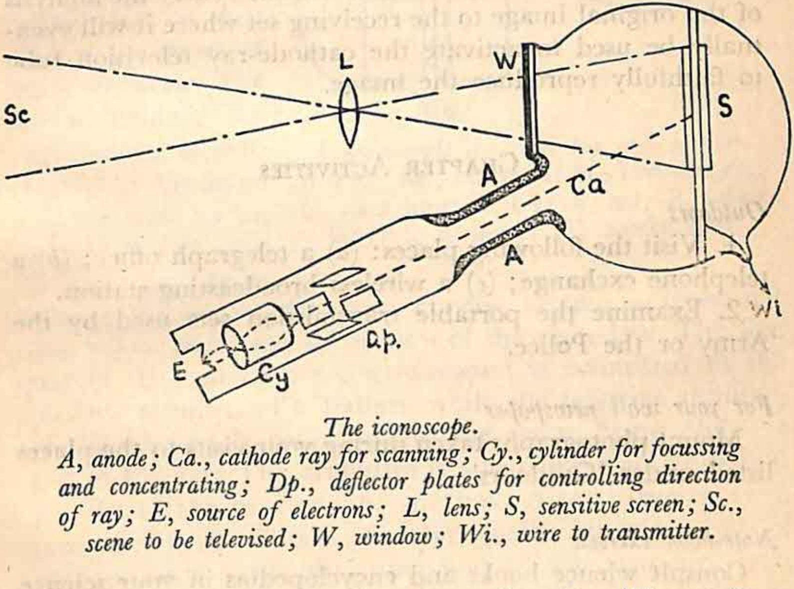
Cathode ray oscilloscope.
C, cylinder; E_1 and E_2, deflecting electromagnets;
F, fluorescent screen; Fil., filament.

end is a fluorescent screen *F*, and at the other end is an 'electric gun'. This consists of a filament *Fil.* heated by an electric current to emit electrons. These electrons are strongly attracted and given a great acceleration by a narrow cylinder *C* above the filament and which is at a high positive potential.

The jet of electrons issuing from the electron gun strikes the fluorescent screen and lights it up; naturally the degree of lighting varies with the number of electrons striking it per unit time, and this depends on the current heating the filament. Now the current heating the filament is regulated by the varying electric currents resulting from the demodulation of the incoming modulated high-frequency waves. This means that finally the brightness on the fluorescent screen varies in accordance with the amounts of light and shade in the various little areas of the image at the emitting station.

To spread out on the fluorescent screen the more or less bright areas in rapid succession and in the same order as at the emitting end, the jet of electrons after traversing the cylinder is made to pass in succession between two pairs of coils E_1 and E_2 at right angles to each other. Each pair of coils is an electromagnet activated by a rapidly alternating current producing a magnetic force which deflects the electron beam periodically to and fro at right angles to the axis of the coil. This results in the electron jet sweeping the fluorescent screen along a series of horizontal lines which gradually move downwards; the horizontal motion being due to the action of one pair of coils, and the vertical motion being due to that of the other pair of coils. The alternating currents acting on these two coils have their frequencies so arranged, that when one horizontal sweep is finished, the other pair of coils bring the jet down one step and the next horizontal sweep takes place; when the bottom is reached, then the jet is again pushed up to the top, to start the whole process again. As electrons are very tiny particles with little inertia, a jet of them can readily be made to move and thus sweep the whole area of the screen at a very fast rate. Naturally the speed and the manner in which the screen is swept by the electron jet, must correspond to the way the image at the receiving end was broken up. This means that the frequencies of the oscillating currents in the two pairs of deflecting coils must be tuned into the process of scanning at the emitting station.

The Iconoscope. The principle of the cathode ray tube is also applied for the rapid scanning of the image at the emitting station. The picture to be televised is focussed by means of a lens on a special screen inside the tube. This screen, called mosaic, consists of a very large number of tiny photo-electric cells close to each other. The various amounts of light and shade of the image focussed on the mosaic produce a corresponding emission of electrons in



The iconoscope.

A, anode; Ca., cathode ray for scanning; Cy., cylinder for focussing and concentrating; Dp., deflector plates for controlling direction of ray; E, source of electrons; L, lens; S, sensitive screen; Sc., scene to be televised; W, window; Wi., wire to transmitter.

all the tiny photo-cells. At the other end of the tube a jet of electrons comes out of the electron gun and passes between the two pairs of deflecting electromagnets at right angles to each other. Thus the whole area of the mosaic is swept in a regular and rapid manner by the electron jet; as and when the jet strikes the successive tiny photo-cells, a photo-electric current corresponding to the intensity of the light at that spot, is sent out through the back of the mosaic screen to the main circuit. Thus in a very rapid and also regular manner all the successive areas of the image are analysed for the amounts of light and shade in them at that moment, and these are transformed into electric currents of corresponding intensities. These are amplified and used to modulate the carrier wave which will then carry the analysis of the original image to the receiving set where it will eventually be used to activate the cathode-ray television tube to faithfully reproduce the image.

CHAPTER ACTIVITIES

Outdoors

1. Visit the following places: (*a*) a telegraph office; (*b*) a telephone exchange; (*c*) a wireless broadcasting station.
2. Examine the portable transmission sets used by the Army or the Police.

For your wall newspaper

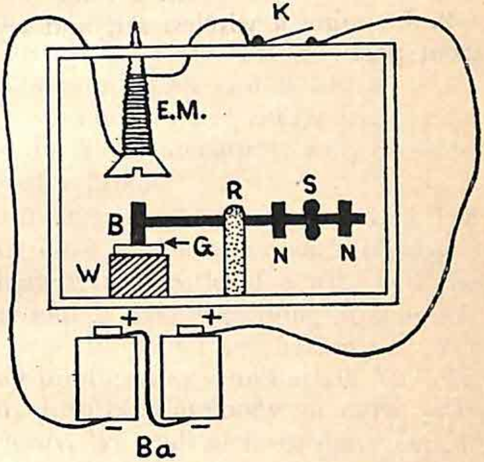
Mount photographs taken during your visits to the places listed under 'Outdoors'.

Note-book exercise

Consult science books and encyclopedias in your science library and make a list of men that made communication through the medium of electricity possible. Write a brief note about each of these men.

At home

1. If you study the accompanying illustration you will see how simple it is to adapt a few pieces of worthless materials to your purpose of making a telegraph key and sounder. The key is merely a strip of metal mounted on the top of the frame of a cigar-box so that one end of it is held down by a screw and the other end is just above the head of another screw. The screw holding the strip down is connected by insulated copper wire to an electromagnet. This is made by wrapping about 75 to 100 turns of wire around a large soft iron screw also fixed to the top of the cigar-box. The free end of the coil of the electromagnet is connected to the positive terminal of a battery while the negative terminal of the battery is connected to the screw below the free end of the key. The armature is a soft iron bolt supported parallel to the base of the cigar-box. A screw-eye screwed into the back of the cigar-box holds up one end of the armature while the other end of the armature rests on a wooden anvil. The anvil has a small piece of glass or porcelain stuck to the top of it by means of sealing wax. Two nuts on either side of the screw-eye ensure that the



A home-made telegraph key and sounder. B, bolt; Ba., battery; E.M., electromagnet; G, glass piece; K, key; N, nut; R, rubber band; S, screw-eye; W, wooden block.

armature does not slip forwards or backwards, while a rubber band holds the armature down when the circuit is open. The space separating the armature from the electromagnet should be about 3 mm.

2. Examine a wireless set, and try to identify the different parts.

CHAPTER III

LISTEN TO THE SOUND

BE as quiet as you can and listen. You will hear so many different kinds of sounds. They may be made by people, animals or machines. There are other sounds which nature makes by means of winds and waters; noisy, frightening ones, like those heard in a thunderstorm; soft, pleasant ones like the babbling of a brook.

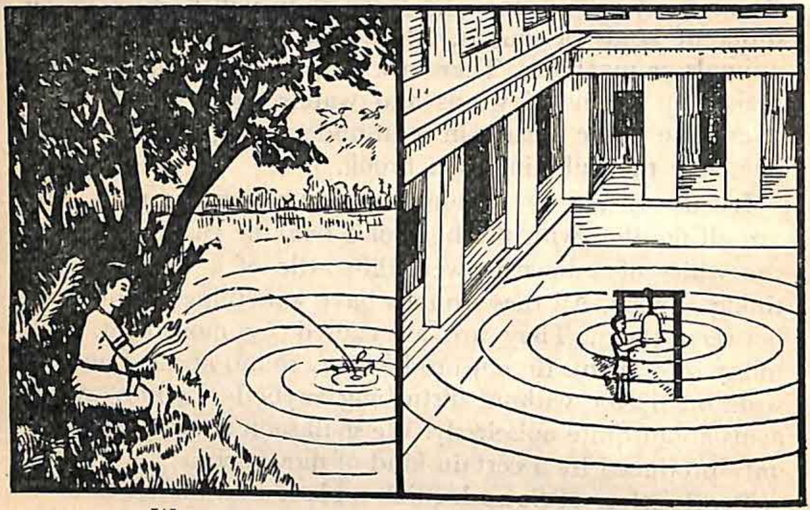
Let us consider for a moment a few common sounds. We are all familiar with the buzz of a bee, the rustle of paper, the whirr of a lawn-mower, the rattle of a cart and the tinkle of glass. All these sounds have something in common between them. They are all caused by movement. Yet many movements do not produce any sound at all. You can walk on tip-toe without disturbing anybody, or move your arms about quite noiselessly. We shall soon see that sound is only produced by a certain kind of movement.

Production of Sound. Stick a blade into the crack of a table. Bend it back and let it go. The blade moves back and forth very quickly and in doing so produces a sound. All sounds are caused by some sudden motion or by a rapid to-and-fro movement which we call vibration.

When the school bell is rung the metal starts vibrating very quickly. The movement in these vibrations is over such a short distance that you cannot actually see it. Sound a bell and then touch the metal immediately. You can feel the vibrations. Your touch, however, stops the vibrations and stops the sound too.

A stone thrown into a tank disturbs the water surface and little waves form and spread in ever-widening circles. These waves spread out in all directions and travel at equal speeds toward the bank. Near the centre, where the movement began, we notice that the waves are strongest.

As each wave advances farther away from the middle it becomes weaker. Sound travels through the air in very much the same way.

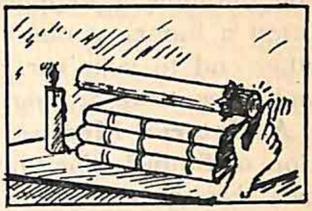


Water waves. *Sound waves.*

The moment something vibrates, the air around it is disturbed and begins to vibrate as well. These vibrations, which spread out through the air as spheres of motion, are very much like waves on water, and are called sound waves.

Make a tube out of cardboard. Tie a thin sheet of balloon-rubber over one end. Place the tube on a few books and bring its end in line with the flame of a candle. A tap will make the rubber sheet vibrate. The vibrations of the rubber sheet cause the air in the tube to vibrate. As the vibrating air 'taps' the flame it begins to flicker.

When sound vibrations reach our ears they 'tap' our eardrums and make them vibrate. We then hear the sound. Strong vibrations give a loud sound. The further we are away from the source of sound the weaker are the sound waves that reach us and the fainter are the sounds we hear.



The flickering flame.

Roll a sheet of newspaper to make a tube. Put one end of the tube to your ear and the other end near a wrist-watch. The ticking of the watch can now be heard. A few of the sound waves are prevented by the paper tube from spreading out and it is these waves that reach your ear.

In the jungle where sudden death lurks in the shadows, animals prick their ears at the slightest sound. They move their ears so as to judge the direction of the sound and catch sound waves better. People who are slightly deaf either cup their hands over their ears or use an ear-trumpet to gather in as much of the sound waves as possible.

Doctors use a listening tube called a stethoscope to hear our hearts beating and our lungs breathing. The best way to

A stethoscope.

Make your own stethoscope.

find out how a stethoscope works is to make your own. Insert a funnel at one end of a rubber tube and put the other end to your ear. Move the funnel over your heart and listen to it beating.

A Material Medium is Necessary for the Propagation of Sound. The vibrations of a sounding body cannot pass through a vacuum but needs some medium to pass through to convey them to our ears. Although the sounds that reach us are conducted through the air to our ears, solids and liquids will conduct sounds as well. In fact, sound travels more quickly and easily through most solids and liquid than it does through air.

Stories are told of how a Red Indian brave used to press his ear to the earth to hear the galloping approach of far-distant horses. In this way he was able to hear the sound of hoof-beats long before they reached him through the air.

Place a wrist-watch on one end of the table and press your ear against the other end. You can hear it tick quite

Listening for hoof-beats.

clearly. Yet at the same distance from it, you would not hear the watch if you relied on the air to bring its sound to you.

Here is an amusing experiment which shows you how well sound travels through solids. Hold one end of a stick between your teeth and ask a friend to listen in at the other end. Tap your head with a ruler. Your friend will smile as she hears the sound. The sound travels through the bones in your head and reaches her ears by way of the stick. The remarkable part of this experiment is that anyone standing near you may not hear the sound of the tap but the listener hears it distinctly.

Sending sounds through a stick.

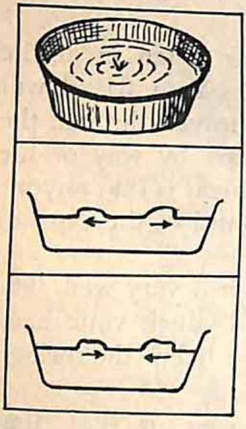
Water, too, allows sound to go through it very well. The next time you visit the swimming pool, duck your head under water and bang two stones together below the surface. The noise is almost deafening.

The most striking experiment, however, is that done near a water-pipe. Press your ear to the pipe while a friend taps a distant part of it with a stone. You are likely to hear three distinct sounds: one coming through the metal, another through the water and a third through the air.

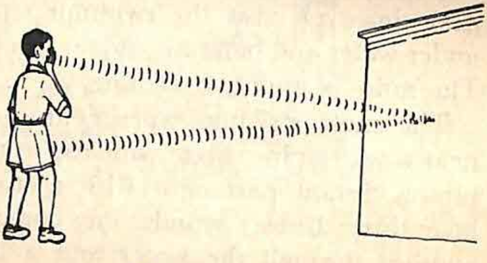
Velocity of Sound. During a thunderstorm you have the opportunity of learning yet another interesting fact about sound. You will notice that lightning is seen before a clap of thunder is heard. The reason is that light travels faster than sound. Sound travels roughly at the rate of one mile in five seconds. By counting the seconds between lightning and thunder you can easily tell the distance of a thunder-storm.

If you watch a game of cricket from afar, you will see the bat hit the ball a little before you hear the knock. So also, if you watch a gun being fired from a mile or so away you notice that there are a few seconds between seeing the puff of smoke and hearing the sound of the shot. These are two further instances of the fact that light travels faster than sound.

Reflection of Sound and Echoes. Fill a pan with water and start a small wave at the centre. See how the wave moves to the edge of the pan, piles up at the sides and ripples back to the centre without losing any speed. A stronger wave will repeat the movement many times. Sound waves are reflected like these water waves. The reflection of sound is usually spoken of as an echo. Anything that stops a sound wave and sends it back again will make an echo. Large, smooth surfaces such as a wall



Reflection of water waves.

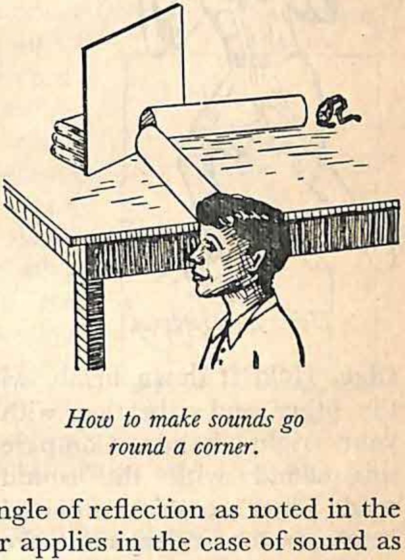


Reflection of sound waves.

or cliff give very good echoes. To get the best results you must stand far away from the wall, at a distance of at least 55 feet, so as to give time for the sound you send out to return again to you, otherwise the sound will become confused with the original sound. Remembering that sound travels a little over 1,000 ft. in a second, an echo is useful for calculating how far away is a reflecting surface.

Sound can be steered round a corner in the same manner as a mirror helps to change the direction of light rays. What mirrors do to light, walls do to sound.

Arrange two cardboard tubes against a smooth stiff sheet of cardboard. Place a wristwatch at the far end of the tube and listen at the end of the second tube. You will hear the ticking of the watch. Vary the positions of the two tubes and see if the relationship between the angle of incidence and the angle of reflection as noted in the case of light striking a mirror applies in the case of sound as well. Repeat the experiment covering the cardboard with rough cloth and again by removing the cardboard strip.



How to make sounds go round a corner.

In a small room that is closed in from all sides echoes will rebound many times. They come back too soon for us to hear them separately, and instead mingle with the sound first sent out. The two sounds together add up to give double the amount of loudness. This is the reason why your voice sounds so much louder when you sing in the bathroom than when you sing in the other rooms.

Similarly, when you speak into an empty bucket your voice sounds louder than if you were to call into a flat pan. Concave surfaces reflect sound better than flat ones.

When you cheer your team to victory on the games-field why do you sometimes cup your hands around your mouth? Megaphones, or speaking trumpets, serve the same purpose, but they also help to direct sound better. This instrument reflects the speaker's voice and more sound reaches the place where it is required.

Using a megaphone.

You have just been reading how sound can be made louder. There are also ways of hushing sounds. Lay a ruler on a table with part of it jutting over the edge. Hold it down firmly with your left hand and start the other end vibrating with your right hand. Compare this sound with the sound made when a cushion is placed between the ruler and the table. The cushion has the effect of hushing the vibrations. Most of the vibrations enter into the cushion and the cushion absorbs them.

Churches, concert halls, cinemas and assembly halls are constructed so that there is a curved recess behind the

Hushing sound.

speaker. This arrangement helps to reflect the voice of the speaker forward and send the sound waves into the hall. To prevent echoes producing an irritating effect, curtains or some other sound-absorbing material are used to cover the reflecting surfaces that would echo back the speaker's voice.

You can reproduce the roar of a tiger, the bark of a dog or the shrill cry of a bird if you can manage to find the right-sized box. Cut a hole in one side of a cardboard box. Tie the end of a string to a small stick and put this end into the cardboard box. Rub resin on the string. Pull the string and hear the sound which comes from the box. Because of the resin on the string your hand moves with a number of short, fast jerks. Each jerk sets the stick vibrating which in turn sets the box vibrating. A small box will vibrate very rapidly and give a high note. A larger box will vibrate less rapidly and give a low note. The same is true of bottles, forks, drums and other things: little sings high, big sings low.

A sounding box.

Vibration of Strings. You can actually see the vibrations in the case of a stringed musical instrument. The thickest string gives the lowest note, that which gives the highest note is very thin. Before playing his instrument a musician may tighten or loosen the strings to get the note he desires. He knows that a tighter string gives a higher note. So also he may move his fingers along the strings while he plays and thus alter the length of the vibrating strings. A long string gives a lower note and a short string gives a higher note. Notes, therefore, depend upon the length, thickness and tension of the object that is vibrating.

Vibration of Air Columns. Take two empty milk bottles of different sizes. Tap each one and listen to its tone. Pour water into the large bottle and keep tapping it until you match its tone with that of the small bottle. You will find that the amount of water in a bottle affects its tone. This experiment can be done in another way.

Two ways of making air vibrate.

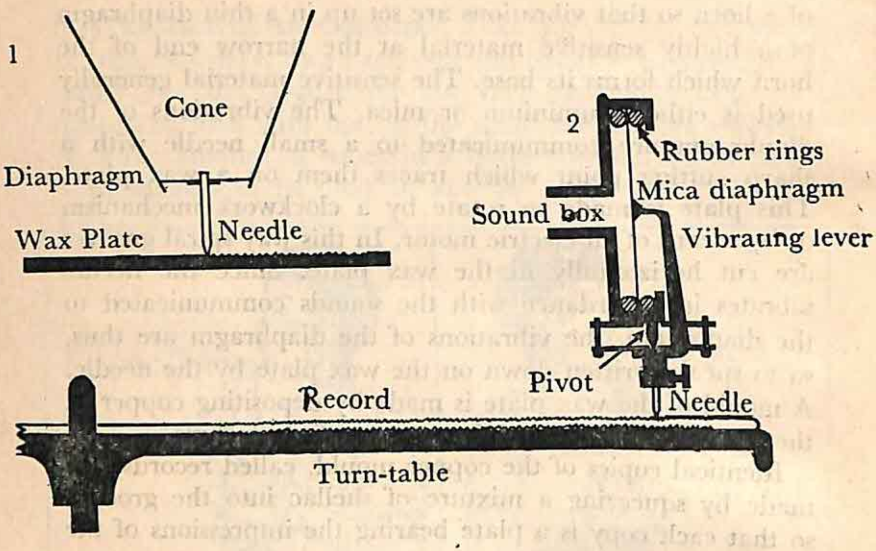
Stiffen your upper lip and gently blow across and slightly down the top of an empty bottle. To make a higher note pour some water into the bottle. Vary the experiment still further by inserting a glass tube into the water. As you raise or lower the tube you change the height of the column of air. Depending on the length of the column of air which is set vibrating by your breath, the note changes from low to high or from high to low. When playing a wind instrument the musician lengthens or shortens the column of air to make the notes on the scale. From 10 paisa whistles to expensive trombones, sound is produced by the vibration of air within them.

The Gramophone. The record for a gramophone is made by collecting sound waves and focussing them by means of a horn so that vibrations are set up in a thin diaphragm of a highly sensitive material at the narrow end of the horn which forms its base. The sensitive material generally used is either aluminium or mica. The vibrations of the diaphragm are communicated to a small needle with a sharp cutting point which traces them on a wax plate. This plate is made to rotate by a clockwork mechanism or by means of an electric motor. In this way spiral grooves are cut horizontally in the wax plate. Since the needle vibrates in accordance with the sounds communicated to the diaphragm, the vibrations of the diaphragm are thus, so to speak, written down on the wax plate by the needle. A mould of the wax plate is made by depositing copper in the grooves by means of the process of electrolysis.

Identical copies of the copper mould, called records, are made by squeezing a mixture of shellac into the grooves so that each copy is a plate bearing the impressions of the grooves.

The gramophone is an instrument for reproducing sounds. The essential parts of a gramophone are a small circular sound box to which a steel needle is attached and a record upon the surface of which is a very fine wavy grooved spiral. The sound box consists of a thin circular mica disc clamped to the edges of the disc with rubber rings. A metal lever is attached to the centre of the disc and a needle is clamped into the lower end of the lever.

When the gramophone is working, the needle rests on the record and moves to and fro and while doing so, accurately follows the course of the wavy lines on the record which were made by the producing needle. The movements of the needle from side to side, that is, its vibrations, are transmitted to the mica disc and the disc in turn vibrates exactly in the same way as the needle. The vibrations of the disc set up sound waves in the air and the original sounds are thus reproduced.

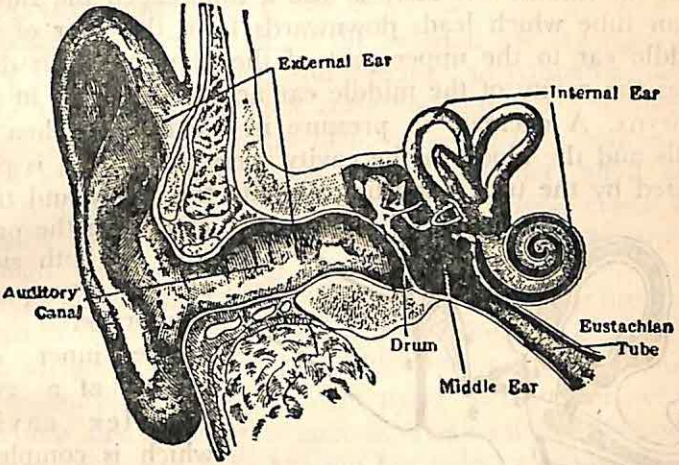


1. *How sounds are 'written down'.*
2. *How sounds are reproduced.*

The Ear. The ear consists of three distinct parts: the external, middle and internal ear.

The external ear consists of an external structure which projects from the side of the head. It surrounds a more or less funnel-shaped opening and serves as a means of collecting sound waves. The opening is the beginning of an open passage called the auditory canal which leads inwards to the middle ear. The mouth of the canal is provided with a number of fine hairs which arrest the passage of minute insects and dust particles into the ear. A number of small glands, which secrete wax, are also embedded in the walls of the canal. Bacteria and insects that gain admission to the canal are entangled in the wax and thus prevented from entering the ear. At the inner extremity of the auditory canal is a very thin membranous partition called the eardrum or tympanic membrane which divides the external from the middle ear. The tympanic membrane is set vibrating by sound waves which are reflected along the canal.

The middle ear is a small irregular cavity in one of the bones of the skull. Stretching across the cavity is a chain of three little movable bones by means of which the vibrations received by the drum are transmitted across the cavity to the inner ear. The first of these bones is hammer-shaped and is called the hammer. The handle of the hammer is attached vertically throughout its length to the inner surface of the tympanic membrane while its rounded end articulates with the second bone called the anvil. This bone has a broad concave head into which the head of the hammer fits. It also has two processes, one of which is attached to the wall of the middle ear by a ligament, while the other articulates with the third bone called the stirrup.



Inner aspect of the drum of the right ear, and the small bones of the middle ear.

The top of the arch of the stirrup is attached to the anvil while the foot plate fits into an opening called the fenestra ovalis which leads to the inner ear. This opening is closed by an oval membrane. Lower down is another opening called the fenestra rotunda which is closed by a round membrane.

In the middle ear there is also a tube called the Eustachian tube which leads downwards from the floor of the middle ear to the upper part of the pharynx. This duct gives the cavity of the middle ear access to the air in the pharynx. A decrease in pressure in the cavity, when its walls and the blood in the cavity there absorb air, is prevented by the tube admitting air into the cavity and thus equalising the pressure on both sides of the tympanic membrane.

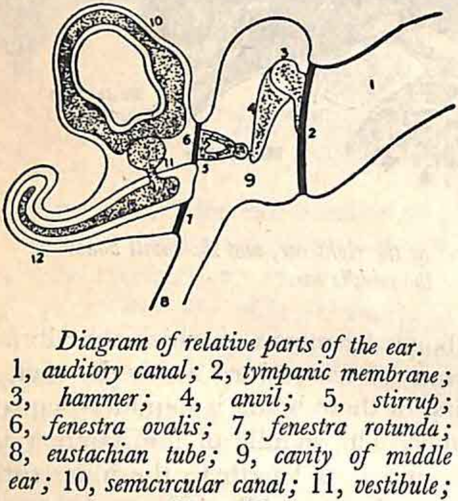


Diagram of relative parts of the ear. 1, *auditory canal;* 2, *tympanic membrane;* 3, *hammer;* 4, *anvil;* 5, *stirrup;* 6, *fenestra ovalis;* 7, *fenestra rotunda;* 8, *eustachian tube;* 9, *cavity of middle ear;* 10, *semicircular canal;* 11, *vestibule;* 12, *cochlea.*

The inner ear consists of a very complex cavity which is completely closed, called the bony labyrinth. In this cavity lies a series of sacs and tubes which contain a lymph-like fluid and are surrounded by another kind of lymph-like fluid. Two little sacs make up the central chamber of the bony labyrinth called the vestibule. Behind the vestibule, and in communication with it are three hoop-like canals called semicircular canals. One of these lies horizontally while the other two lie vertically, but at right angles to one another. In front of the vestibule lies a long spiral canal shaped like a snail's shell called the cochlea which constitutes the essential organ of hearing. The nerve conveying sound impressions to the brain called the auditory nerve is one of the cranial nerves and has its branches connected to the cochlea.

Sound waves collected by the external ear are reflected along the auditory canal and·striking the tympanic membrane set it vibrating at a corresponding rate and intensity. The vibrations of this membrane are then communicated across the middle ear by the hammer, anvil and stirrup and set vibrating the membrane which closes the fenestra ovalis. The vibrations of the membrane travel through the fluid which surrounds the vestibule, semicircular canals and cochlea. The vibrations of this fluid are transmitted to the fluid within these organs. The vibrations of the fluid within the cochlea set up impulses which are transmitted by the auditory nerve to the brain which interprets the impulses as sounds. The semicircular canals are not concerned with hearing but help us to form judgments of the equilibrium of the body and of its movements in various directions.

CHAPTER ACTIVITIES

Outdoors

1. Two cigarette tins and a length of string will help you to set up your own telephone. Punch a tiny hole through the centre of the bottom of each can. Pass the ends of the string through the holes in the two tins and tie knots to prevent the string from slipping out. Have a friend take one phone and ask him to move away until the string is tight. If you wish to attach the connecting line to an object, tie the line to the object with a piece of string.

Make your own telephone.

2. Visit a gramophone factory to see how records are made.

For your wall newspaper

Collect pictures of musical instruments from old magazines and newspapers. Group them on your board under these headings: (1) Stringed instruments. (2) Wind instruments. (3) Percussion instruments.

Note-book exercises

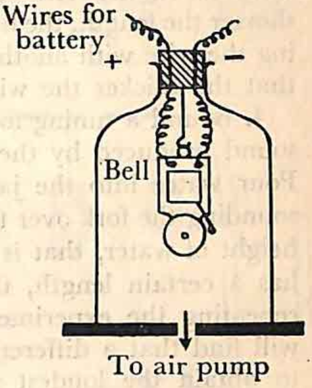
1. Give examples from everyday life which illustrate the facts given in this chapter.

2. Write an essay on the usefulness of sound.

Laboratory work

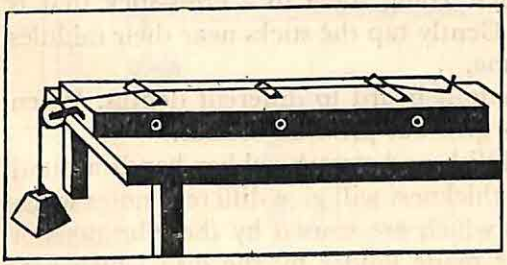
1. Pour some water into a beaker. Strike the end of a tuning fork with a soft hammer and touch the edge of the beaker with the vibrating end of the fork. Note that the surface of water in the beaker is thrown into ripples.

2. Suspend an electric bell inside the receiver of an air pump and set it ringing. Pump out the air from the receiver. As the air is withdrawn from the receiver you will find that the sound gets feebler and ultimately is heard very faintly, although the working of the bell can be seen inside the receiver. This experiment shows that sound is not transmitted through a vacuum but requires a material medium for its transmission. The sound of the bell does not completely die away, because some of it is transmitted by the suspending wires.



To show that sound does not pass through a vacuum.

3. A sonometer consists of a sounding box over which a wire is stretched. One end of the wire is attached to a peg while the other end after passing over a pulley carries a pan. Various weights are placed in the pan to produce the desired tension of the wire. Two wooden bridges are fixed underneath the wire at either end of the sounding box. There is also another wooden bridge placed underneath the wire which can be moved so that any length of wire can be set in vibration. By placing various weights on the pan and by plucking the wire we can prove that the



The sonometer.

greater the tension, the higher is the note produced. By placing the movable bridge under the wire and by suitably adjusting it so that the length of the wire set in vibration is different for the same stretching force we can prove that the shorter the length, the higher is the note produced. By replacing the wire with another of greater thickness we can prove that the thicker the wire, the lower is the note produced.

4. Sound a tuning fork over a tall jar. Note whether the sound produced by the vibrations of the fork is increased. Pour water into the jar, a little at a time, and continue sounding the fork over the jar. You will find that at a certain height of water, that is when the column of air in the jar has a certain length, the sound will become louder. By repeating the experiment with different tuning forks you will find that a different length of air column is necessary to obtain the loudest sound: a longer air column for a tuning fork that sounds a low note and a shorter air column for a tuning fork that sounds a high note.

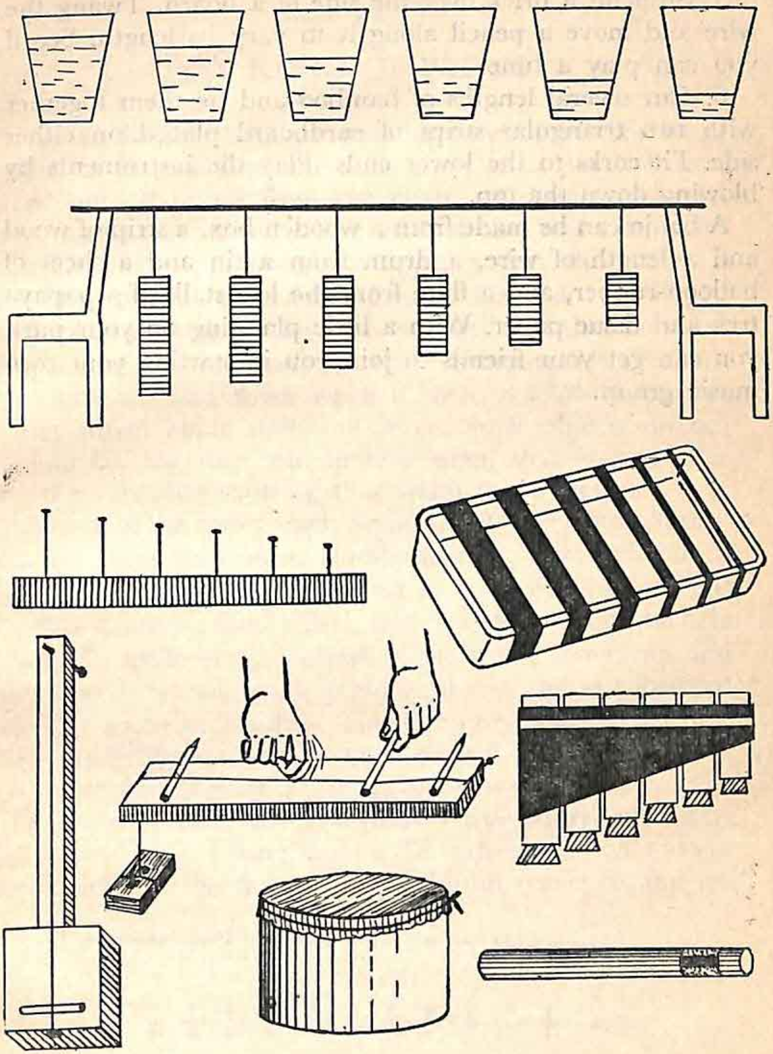
At home

1. Collect a few tumblers and tune them by pouring water into them up to different levels. Put the low-sounding tumblers on the right. Try to play a simple tune by tapping them gently.

2. Saw a stick into several parts, each part slightly smaller than the other. Hang them to a cross-stick that is laid over two chairs. Gently tap the sticks near their middles and try to play a tune.

3. Hammer pins into a board to different depths. When you pluck them they give out pleasant sounds.

4. Obtain a metal dish and stretch rubber bands around it. Bands of different thickness will give different notes when plucked. The sounds which are caused by the vibrations of the rubber bands are made louder by the dish which acts as a sounding box.



Home-made musical instruments.

5. Suspend a brick over the side of a board. Twang the wire and move a pencil along it to vary its length. See if you can play a tune.

6. Cut several lengths of bamboo and tie them together with two triangular strips of cardboard placed on either side. Fit corks to the lower ends. Play the instruments by blowing down the top.

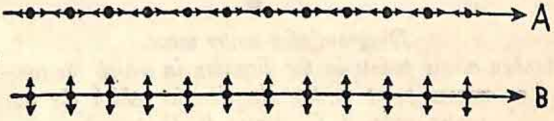
A banjo can be made from a wooden box, a strip of wood and a length of wire, a drum from a tin and a sheet of balloon-rubber, and a flute from the leaf-stalk of a papaya tree and tissue paper. With a little planning on your part, you can get your friends to join you in starting your own music group.

CHAPTER IV

ALL KINDS OF WAVES

WE are all familiar with the circular waves produced when a stone is thrown into the still water of a pond. Waves spread out all round from the centre of disturbance and travel outwards across the surface of the water in ever-widening circles. Although it appears that the water is travelling towards the bank, actually this is not so. If you watch twigs floating on the water you will find that they and other floating objects and, therefore, the particles of water, only move up and down when a wave reaches them, but do not travel along with the wave. Such objects do not rise and fall together, but in succession, that is, one after the other, thereby showing that when the waves pass over the surface of the water, each separate particle does not perform the same movement simultaneously, but each one a little later than the one preceding it. It is therefore evident that it is the wave form which travels forward from particle to particle while every particle of the water moves up and down about its own mean position of rest and not forward from one place to another. The vibratory movements of a series of particles in a medium as described above give rise to a wave and the motion is called a wave motion.

Transverse and Longitudinal Wave Motions. These are the two types of wave motion. In transverse wave motion the particles of the transmitting medium travel to and fro



A, longitudinal waves.
B, transverse waves.

along paths that are perpendicular to the direction in which the wave moves. Examples of transverse wave motion are water waves, the radiant waves in the ether of space such as the waves which convey light and heat energy from the sun, electric waves used in wireless telegraphy and telephony and X-rays. In longitudinal wave motion the particles of the transmitting medium travel backwards and forwards in a path which is along the line which marks the direction in which the wave moves. An example of longitudinal wave motion is a sound wave in air or any other medium.

Terms and Definitions. Look at the illustration of a water wave. The straight line *PQ* represents the undisturbed water line of the section taken. When the wave is advancing

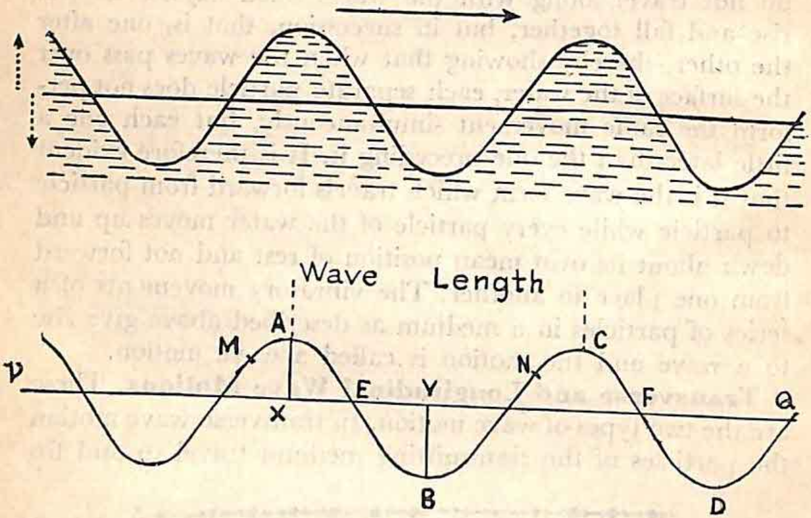


Diagram of a water wave.
The unbroken arrow points in the direction in which the wave moves. The broken arrows point in the direction in which the particles of water move, A, C, crests; B, D, troughs.
AX is the amplitude of the particle A.
YB is the amplitude of the particle B.

in the direction as shown by the arrow, any particle situated at any time on the line is in its mean position. Furthermore, as the wave advances, nearly all the particles are either above or below the water line and are continually moving towards it or away from it. The distance at any time of any particular particle from its mean position is said to be its displacement. In the illustration, *AX* is the displacement of the particle *A* which was originally at *X*, while *BY* is the displacement of the particle *B* which was originally at *Y*. The point *A* on the wave at which a particle is at its maximum displacement is called the crest of the wave, while the point *B* at which a particle is at its lowest point is called the trough of the wave. The maximum displacement of any particle from its normal position of rest is called its amplitude. In the illustration, *AX* represents the amplitude of the particle *A* whose mean position is *X*, while *BY* represents the amplitude of particle *B* whose mean position is *Y*. One complete to-and-fro movement of a particle, during which it passes through all the intervening positions is called a complete vibration: thus the movement from the extreme upper position to the extreme lower position and then back to the upper position is one complete vibration.

In each successive wave there are certain particles like *M* and *N* which at any time have always the same displacement, speed and direction of motion. Such particles are said to have their motion in the same phase. The straight distance between two neighbouring particles in the same phase is the wave-length of the wave. Since the particles on two consecutive crests or troughs are in the same phase, the straight distance between two consecutive crests, i.e. between *A* and *C*, or between two consecutive troughs, i.e. between *B* and *D*, is the wave-length of the wave.

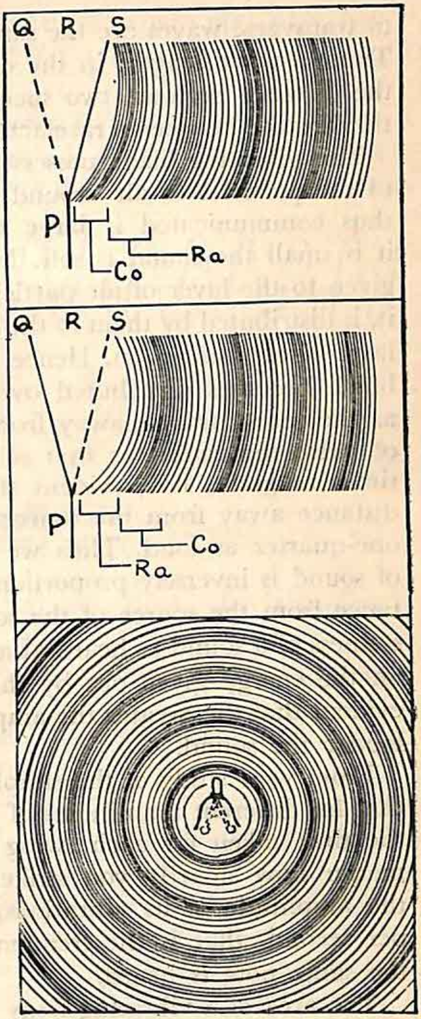
The time taken by any particular particle to go through one complete vibration is the same and is called the periodic time. Successive particles repeat this motion and therefore the number of vibrations completed in one second by every particle of the procession of waves is the same and is called the frequency.

Since waves do not bunch together nor do individual waves separate as they advance, the speed by which they travel is uniform and is called the velocity of propagation. This is measured by the distance travelled over by a wave in one second and is given by the formula $V = N \times \lambda$ where V is the velocity of propagation of the wave, N is the frequency and λ is the wave-length.

Sound Waves in Air. You already know that sound is transmitted in air in the form of longitudinal waves. Consider a vibrating blade which has one end held firmly in the crack of a table. The blade vibrates from one extreme position PQ to another PS. If we now consider the point R vibrating between Q and S we can say that RQ or RS represents the amplitude of the vibration, that is the distance from the position of rest to the extreme position reached.

As the blade vibrates from left to right it strikes the air molecules in front of it thus crowding them together and slightly compressing the air. Owing to the elastic nature of the air, the air which is compressed expands immediately thereafter and in doing so strikes the neighbouring layer of air lying in front of it and compresses it in turn. A series of compression-waves are thus formed which travel outwards through the air from the vibrating blade. As the blade vibrates from right to left the pressure on the neighbouring layer of air is reduced so that there is an expansion or rarefaction of the air and thus a wave of rarefaction follows every wave of compression. A series of alternate compressions and rarefactions are thus formed which travel outwards from the vibrating blade. When these vibrations reach our ears the tympanic membrane vibrates with the same frequency. If the object vibrates with any frequency between 16 and 16,000 times per second we are able to hear the sound.

The sound produced by the vibrating blade travels outwards in all directions provided there are no obstacles in its path. Each compression or rarefaction takes the shape of a hollow sphere and you must imagine this sphere becoming larger and larger as it travels further away from the source of sound. The compressions and rarefactions pass through the air at equal intervals in the same way as the crests and troughs of a procession of transverse waves. In the case of both wave motions there is a transfer of energy by means of vibrating particles. The difference between the two types, however, is in the direction of motion of the particles as compared with the direction of motion of the waves, and except that we substitute compression for crest and rarefaction for trough the terms and definitions as applied



Above and centre: show how a vibrating object makes waves of compression and rarefaction. Co., compression; Ra., rarefaction. Below: spherical expansion and rarefaction of waves spreading out from a vibrating object.

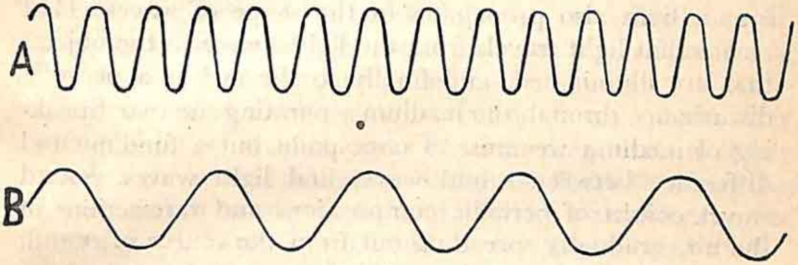
to transverse waves are the same as for longitudinal waves. Thus, a wave length, in the case of longitudinal waves, is the distance between two successive compressions or twice the distance between a rarefaction and the next compression.

The vibrating blade possesses energy which it distributes to the particles of air around it. If the amount of energy thus communicated is large the sound is loud, while if it is small the sound is soft. Moreover, the energy at first given to the layer of air particles immediately surrounding it, is distributed by them to the particles of the neighbouring layer of air and so on. Hence, the energy of the vibrating blade becomes distributed over a larger and larger area as the sound travels away from the blade. Since a sphere of twice the radius as that of another has a surface four times as great, it is evident that when we are twice the distance away from the source of sound it will seem only one-quarter as loud. Thus we may say that the loudness of sound is inversely proportional to the square of the distance from the source of the sound. Since the loudness or softness of a sound as heard at any particular place depends on the energy given out by the sounding instrument it is evident that the greater the amplitude of the vibrations, the louder the sound.

From your study of the simple pendulum you will recall that for different amplitudes of the swing of the pendulum, the time taken for each swing is the same. Similarly, no matter how smartly you strike a tuning fork to increase the amplitude of its vibrations, the number of vibrations per second, that is the frequency, remains the same and the same note is heard.

The area of a vibrating body also has a great deal to do with the loudness of a note. Thus, the note heard when a tuning fork is struck and held in the air is considerably less than when the stem of the vibrating fork is placed against a table or a box, for in the latter instance the vibrations of the fork are transmitted to the wood which also begins to vibrate and in this way a greater volume of air is set in motion.

Tuning forks differ from each other in their frequency, that is the prong of one fork may vibrate much faster than the prong of another. The tuning forks in the laboratory



A, high frequency waves.
B, low frequency waves.

have their frequencies marked on them. By sounding them you will see that forks with a high frequency have high notes as compared with the notes given by forks of low frequency.

Light Waves and Colour. You have read about light rays travelling at enormous speeds even through empty space, so that light signals can reach us from the sun and stars many million miles away in a relatively short time. You have made interesting experiments on the ways in which light is reflected and refracted by mirrors, lenses and prisms. By passing a narrow beam of sunlight through a glass prism you have obtained a spread of gorgeous colours from the red to the violet. Many more experiments could be done, if you had the time, especially to see what happens when two or more rays of light meet or when a beam of light passes through a narrow opening. Such experiments are concerned with phenomena known as interference (superposition of light rays) and diffraction (bending of rays).

It is obvious that light rays carry energy, as is seen clearly in the case of the rays from the sun bringing us energy in the form of heat.

Scientists pondering over all these wonderful phenomena shown by light, have come to the conclusion that like sound, light also propagates in the shape of waves. That means that light travels from the light source to the objects that are illuminated, and finally to the eye as a periodic disturbance through the medium separating the two. Speaking of medium we must at once point out a fundamental difference between sound waves and light waves. Sound waves consist of periodic compressions and rarefactions of the air, gradually spreading out from the source of sound, but as light is propagating even through empty space, the periodic disturbances which constitute light cannot be disturbances of any material medium.

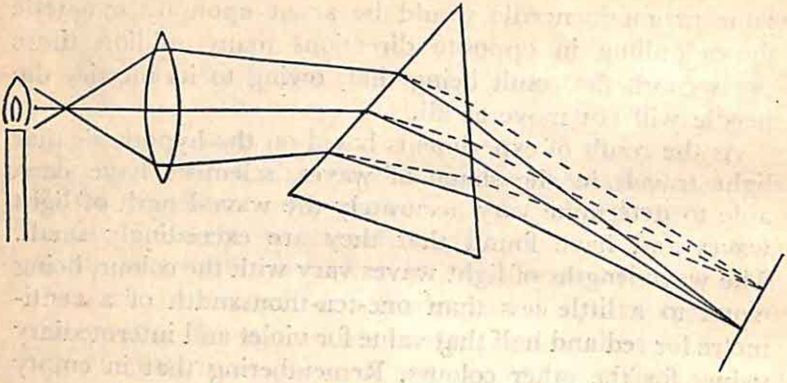
In the case of light waves, scientists tell us that we have to do with electromagnetic waves, and they have very cogent reasons to say so, as will appear a little later. By electromagnetic waves we mean that from the light source there spreads out in all directions periodic electric and magnetic forces which as they move through space will set, or tend to set into periodic vibrations, any electrified or magnetised particles that lie in their paths. Just as a wave spreading out on the surface of the water will set bobbing up and down any piece of cork or wood floating on the surface in the path of the waves.

The words 'or tend to set' are necessary because you might be tempted to place a magnetic needle, pivoted about an axis, in the path of a ray of light and, sure enough, you would find that the needle is not vibrating. The reason is that these electromagnetic vibrations, which constitute the light waves, have very high frequencies, which means that your magnetic needle would be acted upon by magnetic forces pulling in opposite directions many million times per second, the result being that, owing to its inertia, the needle will not move at all.

As the result of experiments based on the hypothesis that light travels in the shape of waves, scientists have been able to determine very accurately the wave-length of light waves and have found that they are exceedingly small. The wave-lengths of light waves vary with the colour, being equal to a little less than one-ten-thousandth of a centimetre for red and half that value for violet and intermediary values for the other colours. Remembering that in empty space light travels with a velocity of 300,000 kilometres per second, it follows that the number of wave-lengths over a distance covered by light in one second, is equal to the velocity divided by the wave-length, that is 30,000 million centimetres divided by 5 one-hundred-thousandths of a centimetre, which comes to 600 million million wave-lengths. That means that the source producing these vibrations vibrates with that same frequency of 600 million million cycles per second.

You may be surprised at these very minute, ultra-microscopic wave-lengths of light waves, or their equally fantastic high frequencies, but you may rest assured that scientists have been able to measure these very minute wave-lengths with an amazing degree of accuracy. Thus as a result of very refined measurements they are able to tell us the exact number (plus a fraction) of wave-lengths of a particular red colour which equals the length of the standard metre.

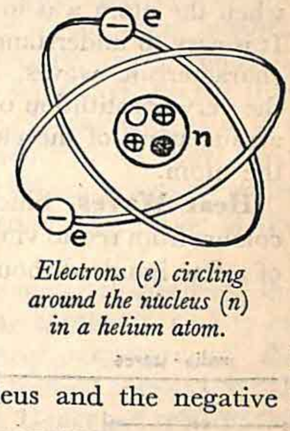
Now we have something clear and definite to distinguish the various colours, each having a definite wave-length. Of course in this way we can distinguish many more than the traditional seven colours of the rainbow, every slightly different shade having its characteristic wave-length. An



Arrangement for producing a spectrum.

important point to note is that if the light from a burning gas, or from an electric spark through a gas or between two metal rods, is passed through a narrow slit and then spread out by means of a glass prism, a set of narrow coloured lines appear, separated by dark spaces. The wave-lengths of each of these can be determined by the usual methods, and it has been found that each atom and each molecule, when properly excited by heat or by electricity, gives off its own characteristic spectrum. That means that each substance can be identified by the characteristic light waves it emits when in the luminous state.

Origin of Light Waves. The question naturally arises as to how a luminous substance sends out electromagnetic periodic disturbances, which constitute the light waves. Just as a rod dipping periodically in the water sends all around it on the surface of the water a regular procession of waves, or as the vibrating string of a violin sets up in the space around it a series of periodic compressions and rarefactions of the air forming sound waves, so also in the case of the light source, there must be some periodic movement of some agent causing a periodic variation of electric and magnetic forces all around it. In the chapter on electricity it is shown that moving electrified particles produce magnetic forces in the space all around it, and if the motion of the electrified particles varies, the magnetic forces also vary and are accompanied by varying electric forces. Therefore the obvious suggestion is that in the atoms and molecules there must be electrified particles which by their periodic movements produce periodic electric and magnetic forces in the space all around it. We now know quite definitely that atoms and molecules contain electrified particles which are in constant motion around each other.

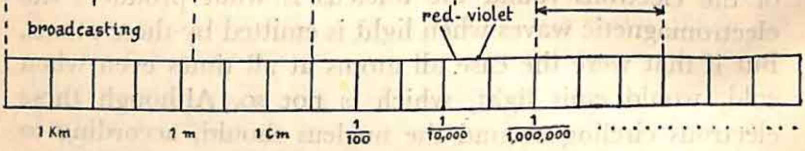


Electrons (e) circling around the nucleus (n) in a helium atom.

It is assumed that each atom consists of a central nucleus, containing practically all the mass, and having a positive electric charge; around this nucleus circle a few tiny negative electric particles called electrons. The electrons circle around the nucleus, like the planets around the sun, and in this case the centrifugal force, due to the circular movement, is exactly balanced by the attractive force between the positive nucleus and the negative electrons.

You may be tempted to think that this periodic movement of the electrons round the nucleus is what produces the electromagnetic waves when light is emitted by these atoms. But if that were the case all atoms at all times even when cold, would emit light, which is not so. Although these electrons circling around the nucleus should, according to the classical theory, constantly emit electromagnetic waves, yet we must say that in fact, it is not so. A possible explanation might be that the various waves emitted in this process just cancel each other's action in the space all around the atom. When, however, the atoms are heated, or otherwise excited by passing an electric discharge through a crowd of them, they are thrown into violent agitation, colliding with each other. As a result of these collisions, the atoms receive additional energy, which is absorbed by the electrons now circling in other wider orbits. But soon the atoms tend to return to their normal state with the regular orbits of the moving electrons, and in this process the excess energy that had been absorbed is now given out in the shape of electromagnetic disturbances, which are the differences between the periodic motions of the electrons when the atom was in the excited and in the normal state. It is easy to understand why each atom will give off its own characteristic waves, because these naturally depend on the very constitution of each atom, that is on the particular arrangement of the electronic orbits around the nucleus of the atom.

Heat Waves. Since the wave-lengths of the different colours from red to violet are spread out over a narrow range of a few hundred-thousandths of a centimetre, the question



Electromagnetic spectrum.
As you move to the right from one division to the next, the wave-lengths decrease by 1/10th.

naturally arises whether there are any other electromagnetic waves of either longer or shorter wave-lengths. Our eye could not possibly perceive them as it is only sensitive to the above range of colours, but what about trying to detect their possible existence by some other means?

By means of a mirror send a beam of sunlight through a narrow slit in the wall of a darkened room, and inside the room, by means of a prism, spread out the light into a coloured patch, containing all the colours from red to violet. If a photographic plate is placed at the colour patch and is then developed, we shall find that the plate has been affected by the sun's rays not only over the region of the coloured patch, but also further on either side, beyond the portions of the red and violet. Hence we are quite justified in speaking of infra-red and ultra-violet rays, which in every way are similar to the visible light rays, except that they are not perceptible by the eye. Measurements of the wave-lengths of these electromagnetic waves show that on the infra-red side their wave-lengths are longer, while on the ultra-violet side they are shorter than those of the visible rays.

If we pass a thin sensitive thermometer slowly over the various coloured patches of the solar spectrum, as formed by the prism, we find that the heat registered by the thermometer increases as we move from the violet to the red and beyond it into the infra-red. Hence we refer to the infra-red rays as the heat rays. Experiments show that these heat rays extend very far into the infra-red region of the spectrum, which means that the heat rays, being electromagnetic waves, just like visible light, have wave-lengths of gradually increasing length, extending from one-ten-thousandth of a centimetre to nearly one-hundredth of a centimetre. The methods of producing these heat waves gradually change as the wave-length increases; however, they are essentially produced by sources of intense heat, emitting in the present case heat rays invisible to the eye, but easily felt by the hand if placed in the path of the rays.

The methods of measuring the wave-lengths of these heat waves also gradually vary with the wave-lengths, until finally we reach a most interesting transition stage, which provides the clinching argument in favour of the assertion that all these rays are really electromagnetic waves.

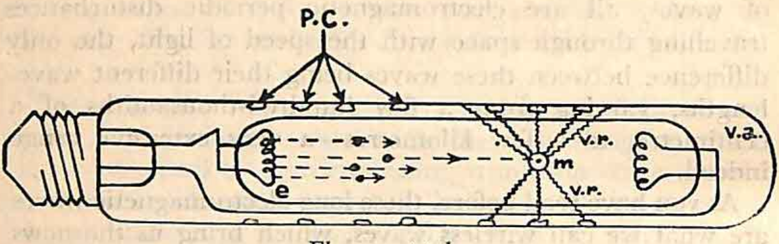
Wireless Waves. As has been explained before, when an electric current is made to flow periodically backward and forward in an electric circuit, all around the circuit periodic electromagnetic disturbances are produced, gradually spreading out in the shape of electromagnetic waves. In the present case, these electromagnetic waves were detected at various places around the circuit by the electric oscillations they in their turn set up in an electric circuit properly designed (tuned in). So it was relatively easy to measure directly the frequency of these electric oscillations and therefore of the electromagnetic waves producing them. These experiments also showed that these waves were travelling with the same speed as that of light. The wave-lengths of these waves were found to be in the order of a few kilometres, then, with more refined apparatus, waves could be produced of wave-lengths measuring only a few metres, and even a few centimetres, until finally they reached the region of the wave-lengths of the longest heat waves. Both these ultra-short electromagnetic waves produced by electric oscillating circuits and the very long heat waves produced in the usual way, were successfully studied and analysed with one and the same type of apparatus thus proving beyond any doubt that both types of waves are identical in their essential properties. This naturally means that right down from ultra-violet rays through the visible rays and heat rays up to the long electromagnetic waves we have but one and the same type of waves, all are electromagnetic periodic disturbances travelling through space with the speed of light, the only difference between these waves being their different wave-lengths, varying from a few hundred-thousandths of a centimetre, to a few kilometres—a very extensive range indeed.

As you have read before, these long electromagnetic waves are what we call wireless waves, which bring us the news from distant places by what is commonly known as radio transmission.

Ultra-violet Rays. We must return once again to the solar spectrum as produced by the action of a prism spreading out a narrow beam of sunlight into its constituent colours. We have seen that beyond the violet patch of the spectrum there are still sun-rays that are active and which affect the photographic plate placed there. These are called ultra-violet rays, or also actinic rays, because of their action on the chemicals in the photographic plate as well as on many other substances. These rays are also studied and analysed by methods similar to those used for studying the visible rays, and so it is found that they too are electromagnetic waves of gradually decreasing wave-lengths, which may be as much as a hundred times smaller than the wave-lengths of the violet, that means they are about one-millionth or less of a centimetre.

Ultra-violet rays are produced by the sun, but, fortunately for us, the ultra-violet rays of short wave-length coming from the sun are absorbed by some of the upper layers of the atmosphere, thus protecting us against these dangerous rays. Ultra-violet rays can also be produced by passing an electric discharge through mercury vapour contained in a closed tube free from most other gases.

Ultra-violet rays when falling on certain substances, produce 'fluorescence', that means that these so-called fluorescent substances when illuminated with invisible ultra-

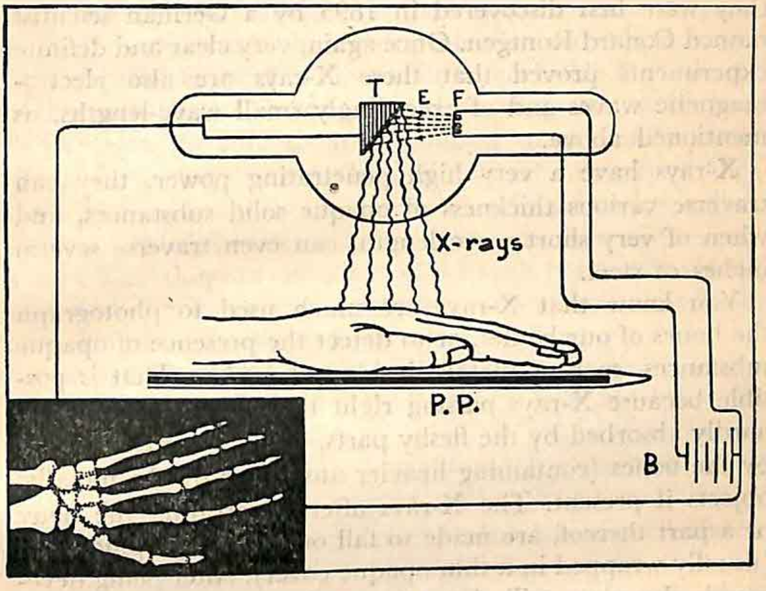


Fluorescent tube.
e, electrode emitting electrons; m, mercury atom when hit by electrons, emits ultra-violet rays, which in turn activate the phosphor crystals; p.c., phosphor crystals; va., vacuum; v.r., visible rays.

violet rays give off visible light of various colours, according to the nature of the fluorescent substance. This is the way a 'fluorescent tube' works; inside it an electric discharge of fast-travelling electrons passing through mercury vapour produces ultra-violet rays which fall on the fluorescent salts spread over the inner wall of the tube, these in turn fluoresce and give off a mixture of colours resembling that of 'daylight'.

Because of their shorter wave-length, ultra-violet rays exert a more intense action on various substances. They are responsible for the tan of the skin, when exposed to the sun-rays for some time, and for sunburn when the exposure lasts too long. Ultra-violet rays of short wave-length are powerful germ-killers, hence special ultra-violet lamps are used for sterilising water, milk, or the air in classrooms, public buildings, hospital operating theatres and so on.

X-rays. Having come down in the scale of wave-lengths of electromagnetic waves from a few kilometres to a few millionths of a centimetre there seems no reason to stop at this particular small length, and in fact we can still go lower down on this scale of ultra-small wave-lengths. This brings us to the famous X-rays which are also electromagnetic waves of which the wave-lengths are a hundred or even a thousand times smaller than the smallest ultra-violet waves referred to above, which brings us to one-thousand-millionth of a centimetre.



X-ray tube.
Inset: X-ray photograph of bones of hand and wrist.
B, battery; E, stream of electrons; F, filament; P.P., photographic plate; T, target.

X-rays are produced in so-called X-ray tubes. An X-ray tube is a glass bulb in which there is a high vacuum. Inside the tube on one side there is a thin metallic filament *F* which on being heated by the current from a battery *B* emits a stream of electrons *E*; on the other side in the tube there is a small metal plate (the target) *T* maintained at a very high electric potential relative to the filament, the result is that electrons are violently attracted towards the plate and on striking it with great force naturally communicate much energy to the atoms and their electrons in the plate. This results in the emission of powerful rays, called X-rays, because of their absolutely mysterious nature when they were first discovered in 1895 by a German scientist named Conard Rontgen. Once again, very clear and definite experiments proved that these X-rays are also electromagnetic waves and of exceedingly small wave-lengths, as mentioned above.

X-rays have a very high penetrating power, they can traverse various thickness of opaque solid substances, and when of very short wave length, can even traverse several inches of steel.

You know that X-rays are much used to photograph the bones of our bodies, or to detect the presence of opaque substances, such as metals, inside our bodies. That is possible because X-rays passing right through our bodies are hardly absorbed by the fleshy parts, but are more absorbed by the bones (containing heavier atoms) or by the metallic objects if present. The X-rays after penetrating the body or a part thereof, are made to fall on a photographic plate (usually wrapped in a thin opaque cover). After being developed, the plate will show the outline of the bones or of the metallic object standing out in clear contrast against a soft background corresponding to the absorption due to the fleshy parts.

Nowadays X-rays are much used to inspect iron castings or welded joints of plates for any possible flaws or defective spots.

Another very interesting application of X-rays is their use in the study of the structure of crystals. The regular outer geometrical shape of crystals is naturally attributed to the regular arrangement of atoms and molecules constituting the crystal. The crystal must consist of regular layers of atoms or molecules separated by uniform distances. A beam of X-rays directed on a crystal will penetrate inside and the X-rays will be reflected by these layers of atoms in different directions. These rays on emerging from the crystal are received on a photographic plate, on which they are recorded as dark spots. From a detailed study of the pattern of these spots, scientists are able to determine the arrangement of the atomic layers inside the crystal.

Gamma Rays. These too are electromagnetic waves and of wave-lengths still about a hundred times smaller than those of ordinary X-rays. Gamma rays are being spontaneously and continuously emitted by certain substances called radio-active substances, such as radium, uranium and several others. That they are essentially of the same type as the visible rays and the long electro-magnetic waves and that their wave-lengths are as small as mentioned above, is again shown by very precise and reliable experiments and measurements. Because of their very short wave-length, these gamma rays have a very great penetrating power and have a very powerful effect on the objects on which they fall. You know that radium is used for treatment of that dreaded disease called cancer. It is specially used for this treatment because of the special action of the gamma rays on the diseased tissues, which they strongly attack and eventually destroy, whereas their action on the healthy tissues around the tumour is much less destructive.

Radiant Energy. You have just read a very brief summary of a very important class of physical phenomena, that of radiant energy, which refers to a special, yet very general process by which energy is transmitted even over immense distances and at incredible speeds. In each case the origin is some periodic electric disturbance produced in various ways, either in an electric circuit, or more generally inside the atom itself, this results in the emission of a procession of electromagnetic periodic disturbances spreading out in all directions and when meeting an electric particle they set up corresponding vibrations with at times very striking results.

Chapter Activities

Outdoors

1. Tie one end of a rope to a post at about the height of your waist. Pull on the rope, and at the same time, flick the free end in your hand up and down. By doing this you will make waves travel along the rope. Note that each section of the rope bobs up and down. Rapidly move your hand from side to side. You will find that the number of waves have increased and also the greater the number of waves the shorter is the distance between each wave and the next.
2. Make a number of children form a single row. Ask them to sit on their haunches. Give each child a serial number, the child at the extreme left No. 1, the child next to him No. 2 and so on. Now, call out the numbers in serial order starting with No. 1. On hearing his number a child should slowly rise up and sink down on his haunches again. Note that as you call out the number, although each child remains in his place, yet a wave passes along the line.
3. Visit an X-ray clinic and see how X-rays are taken.

For your wall newspaper

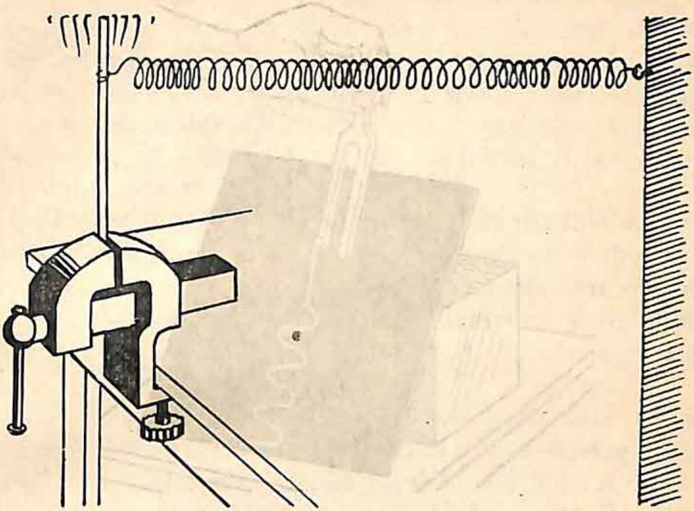
Obtain X-ray photographs and mount them on your board.

Note-book exercise

Make a summary of this chapter.

Laboratory work

1. Fix a strip of steel in a vice. Attach one end of a spiral spring to the top of the steel strip with sealing wax and the other end of the spring to a hook in the wall as shown.

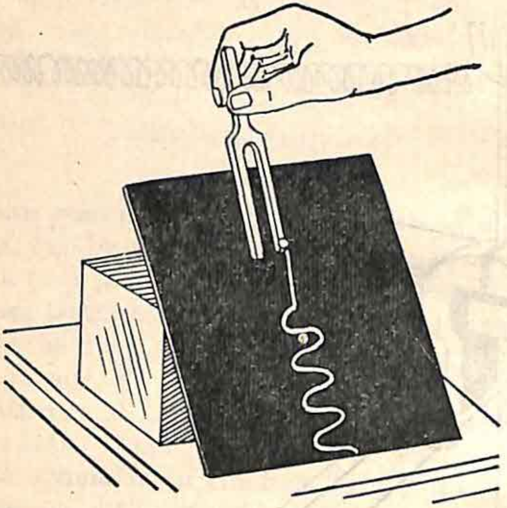


To show how a spiral spring can be made to vibrate in waves.

Make the rod vibrate. Note that the spirals nearest the rod are alternately compressed and separated and these compressions and separations are communicated to the neighbouring spirals throughout the length of the spring. As the rod ceases to vibrate the waves of motion cease as well.

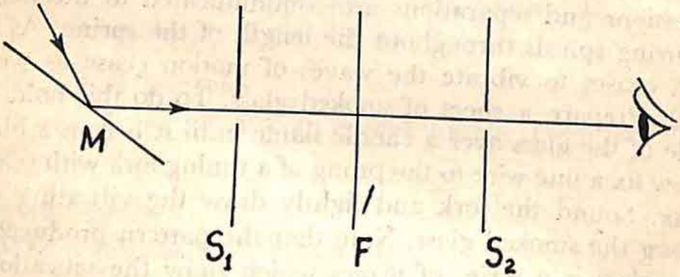
2. Prepare a sheet of smoked glass. To do this hold one side of the glass over a candle flame until it becomes black. Now fix a fine wire to the prong of a tuning fork with sealing wax. Sound the fork and lightly draw the vibrating wire along the smoked glass. Note that the pattern produced on the glass is a series of waves which show the vibration of the wire. Repeat the experiment with tuning forks of different frequencies.

3. Set up the apparatus for the following experiment. Light from the sun is reflected by a mirror *M* on to a screen



To show the wave pattern produced by a vibrating tuning fork.

S_1, with a small narrow slit, the light then passes through a red glass F and is observed through a narrow slit in a

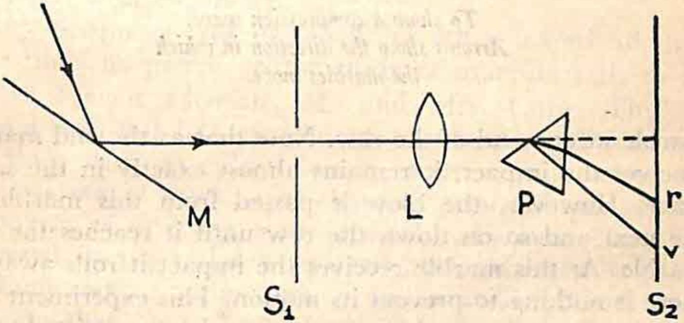


An arrangement to observe diffraction fringes

second screen S_2, the slits in the two screens being parallel. You will see a set of narrow dark and bright bands spreading out at right angles to the length of the slit. Replace the red glass by a yellow or green glass, and see how the width of the bands varies with the colour. By using various screens S_2 with slits of different widths, you will see that the width of the bands varies with the width of the slits. These are phenomena of diffraction easily explained if we assume that light consists of waves.

4. Repeat the above experiment, but in the first screen S_1 make a very small circular hole, and instead of the screen S_2 stretch out a piece of cloth, cotton or silk; the coloured pattern observed varies with the diameter of the fibres. This was a method used in former days to compare the diameter of cloth fibres.

5. To produce a solar spectrum, the light from the sun after reflection by a mirror M is made to pass through a hole about 2 cm. wide in a screen S_1, then the light is focussed on a screen S_2 by means of a lens L. Now a prism P is placed between the screen S_2 and the lens, and the solar spectrum is spread out on the screen. Three rather sensitive thermometers are placed with their bulbs respectively in the green and red regions and a little beyond the red, and the rise of the mercury threads observed in all three.

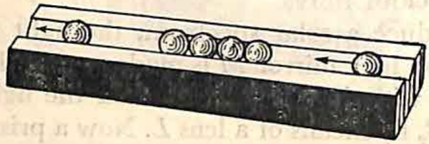


An arrangement to produce a spectrum.

6. Making the usual arrangements to observe a spectrum as explained in the chapter on light in Book 3, use as light source a bunsen burner in which you place successively a bit of asbestos soaked in weak solutions of sodium chloride, lithium chloride, potassium chloride and strontium chloride. Observe the different spectra of the respective substances.

At home

Place a row of about 6 marbles in the pen groove of your desk so that each marble touches the one next to it. Roll another marble along the groove so that it strikes the marble at one end of the row. Note that as the end marble receives the impact, it remains almost exactly in the same place. However, the blow is passed from this marble to the next and so on down the row until it reaches the last marble. As this marble receives the impact it rolls away as there is nothing to prevent its motion. This experiment will help you to understand how waves can be transmitted without the particles of the medium moving very far.



To show a compression wave. Arrows show the direction in which the marbles move.

CHAPTER V

ATOMIC ENERGY

In the year 1896, the French scientist H. Becquerel experimented with various types of crystals to study their phosphorescence under the action of sun rays. Quite by accident he discovered that amongst his crystals, those containing uranium, spontaneously emitted mysterious and powerful radiations which would even traverse black paper in which his photographic plates were wrapped, and cause the fogging of these plates. This was very similar to the action of the equally mysterious X-rays discovered only a year earlier. In fact just like X-rays, the rays emitted by the uranium salts were found to interfere with electrical measurements, because they tended to discharge conductors charged with electricity.

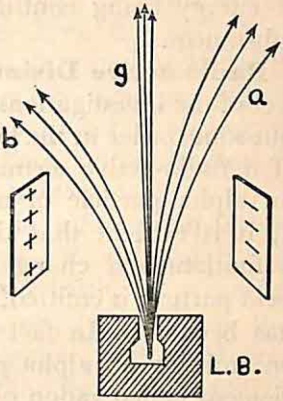
As Becquerel was occupied by other investigations at the time, he passed on the study of uranium salts to two other French scientists, Mr and Mrs. Curie. They set about their task in a most energetic manner, and as a result of their truly herculean labour, were able to show that quite a few of the heavier elements possessed this peculiar property of emitting some special radiations. They discovered in particular a new element, which they called radium, whose radio-activity was a million times more intense than that of uranium. The research was carried out by other scientists as well, and quite a number of radioactive elements were discovered, most of them of great atomic mass.

Radiations from Radio-active Substances. When these radiations are directed on fluorescent substances they make them glow with most wonderful colours, varying with the nature of the substance. As already mentioned, these rays tend to discharge conductors charged with electricity. This is attributed to the ionising action of these rays. This means that the rays on passing through the air collide with the gas molecules and knock off an electric charge now and then. The result is that soon the air is filled with electrified particles, called ions, which help to discharge the charged conductors.

These rays are very powerful indeed, for, as you know, when directed into tumours, such as cancer, they can destroy the cancerous cells, and at times bring about a complete cure.

Another remarkable phenomenon about these radio-active substances is that they continuously give off heat, so that they tend to maintain themselves at a higher temperature than their surroundings. The amount given off is quite substantial, in the case of radium the energy thus produced in a few days is greater than the energy derived from the explosion of an equal weight of the forceful explosive T.N.T. After the explosion of T.N.T. nothing of the original substance is left, the whole of it having been transformed into other inert substances. But in the case of radium it continues to give off heat and radiations spontaneously and steadily at practically the same rate. Even after a hundred years the activity of a given amount of radium will only have decreased by four per cent. We shall of course have to try to find the key to this mystery of the continuous and spontaneous production of large amounts of energy without any appreciable change in the substance, or without any energy being supplied from outside.

Alpha, Beta and Gamma Rays. Whereas the Curies were mainly concerned with the chemical investigations about the radio-active substances, an English physicist, E. Rutherford, and his collaborators focussed their attention more particularly on the physical aspects of the phenomenon. First of all they found that these special radiations were not all of the same type. By passing them between the poles of a



Separating alpha (a), beta (b) and gamma (g) rays. L.B., lead block.

strong magnet, or between two plates charged with positive and negative electricity respectively, they found that the original narrow beam of rays broke up into three. One of these went straight on, undisturbed by the magnetic or electric force, the other two were deflected on opposite sides and by different amounts. The three sets of rays were given the names of alpha, beta and gamma rays.

Since the alpha and beta rays are affected by electric and magnetic forces, they must consist of moving electric particles. The gamma rays are unaffected by such forces and appear to be very similar to X-rays. In fact further investigations showed that gamma rays are electro-magnetic waves of extremely small wave-length, travelling with the speed of light, in everything similar to hard deep-penetrating X-rays.

The alpha rays were found to consist of particles of mass equal to four times that of the hydrogen atom, and carrying two positive elementary charges of electricity. Their speed ranges up to 20,000 Km. per second, and they are fully absorbed and stopped after traversing a few centimetres of air or a sheet of paper.

The beta particles consist of very fast travelling electrons, the elementary particles of negative electricity and of negligible mass. Their speed at times approaches that of light. They can traverse several metres of air or even a thin foil of aluminium before they are completely absorbed.

All this once again indicates clearly the enormous amount of energy being continuously emitted by the radio-active substances.

Radio-active Disintegrations. Another important object of the investigations of Rutherford and his group, was to put some order in the large family of radio-active substances. If a radio-active element, like uranium or radium, emits an alpha particle of mass 4 and positive electric charge 2, it is evident that the original element has undergone a fundamental change. The same must be said when a beta particle is emitted, which means that a negative charge has been lost. In fact it was found that a radium atom on emitting an alpha particle, is transformed into another element called radon or radium emanation which is a gas. This again by emitting another alpha particle becomes another element and so on.

As a result of painstaking observations and tedious calculations, Rutherford, especially with the assistance of another scientist named Soddy, was able to draw up a few family-trees of the radio-active substances. To take one instance, one such radio-active series starts with uranium, the heaviest element of mass 238. By giving off an alpha particle, it changes into another; this in turn by a similar process changes into another and so on. Through a succession of emissions of alpha and beta particles, with the emission of gamma rays thrown into the bargain, they could trace the successive offsprings of the patriarch uranium. On the way down they found radium as one of the series, and right at the bottom of the disintegration series was the very common element lead. All the radio-active elements can thus be fitted into one of the three family-trees, the end product of each of them being lead.

We should note that here we find realised in nature the dream of the alchemist, namely the transmutation of one element into another. Such a transformation is going on all the time in nature and in a most orderly manner.

Scientists have been able to determine the exact proportion of atoms that in a given time break up and are transformed into the next element in the series. Thus in the case of radium it takes 1,590 years for half the number to break up, whereas in the case of its immediate offspring radon, it takes only 3·82 days, and for its ancestor, uranium, it takes 4½ thousand million years. Each such number is called the half-life of the corresponding element.

Having gathered such a wealth of information about the radio-active disintegration process, Rutherford began to think about the very structure of the atom. He was very well placed to do so, since he was actually witnessing the transmutation of one element into another, and could examine in detail the building stones that were discarded in the breaking down of one atom into another.

Before proceeding further it is essential to refer briefly to two fundamental notions regarding chemical elements.

Atomic Mass and Atomic Number. As you know, chemical elements are the ultimate particles into which a substance can be decomposed by chemical means. The respective masses of these elements are determined by comparison with that of oxygen, whose mass is put at 16. This is done because in this way the mass of the lightest element, hydrogen, comes out to be 1. The next lightest, helium, has a mass 4, in the same way carbon has mass 12, chlorine 35·5, calcium 40, iron 55·8, gold 197·2, and so on up to the heaviest, uranium 238. These numbers are referred to as the atomic masses or weights of the elements.

All the elements are then arranged in order of increasing atomic masses, and the ordinal number of the element in the series is referred to as its atomic number. Thus the atomic number of hydrogen is 1, that of helium 2, that of carbon 6, of oxygen 8, of iron 26 and for the heaviest, uranium, it is 92. It was gradually realised that the atomic number of an element is more important than its atomic mass and the identity of an element is established by its atomic number which implies very definite chemical properties. In fact in quite a number of cases, it was found that elements having the same atomic number and therefore having identical chemical properties, have different atomic masses. Such elements are called isotopes (=same place), because they occupy the same place in the series of chemical elements, as they are indistinguishable by any chemical methods. An example is hydrogen, of which there exist three varieties with masses respectively one, two and three; at the other end there is uranium of which the different isotopes have masses 233, 235 and 238.

When we say that the mass of oxygen is 16, this does not mean that one atom of oxygen weighs 16 grams, it only helps to express the relative masses of the different atoms. As a matter of fact, even a millionth of a gram of hydrogen contains three-hundred-thousand-million-million atoms, in mathematical language this is expressed as 3×10^{23} atoms per gram of hydrogen. Of course for oxygen the number per gram would be sixteen times less, and so on for the other elements.

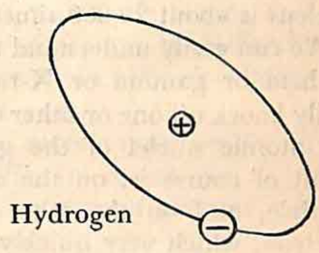
Fundamental Particles. Since some atoms do actually break up, as we have seen in the case of radio-active elements, we can no longer admit that an atom is really unbreakable, in spite of its name (atom =indivisible). It seems obvious that the heavier atoms are built up from lighter particles. Hence the need of saying a few words about the so-called elementary or fundamental particles, which apparently cannot be further split up into smaller bits. The three most fundamental particles are the electron, the proton and the neutron.

The electron, whose existence and individuality was definitely established by an English physicist, J. J. Thomson, in 1897, is a tiny particle of mass $\frac{1}{1840}$ that of an atom of hydrogen and carries the elementary charge of negative electricity. By elementary charge of electricity is meant that the electric charge on a body can only increase or decrease by one such charge or a multiple thereof, but never by a fraction of it.

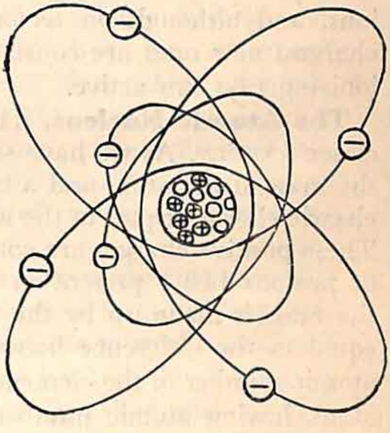
The proton is a particle of practically the same mass as that of the hydrogen and carrying the elementary charge of positive electricity. In fact a proton is a hydrogen atom which has lost an electron.

The neutron is a particle of practically the same mass as the proton, but carrying no electric charge, hence its name.

Atomic Structure. As a result of his musing on the disintegration of radio-active elements, Rutherford arrived at the conclusion that each atom is a planetary system on a miniature scale. An atom consists of a very tiny core called nucleus, around which move in circular and elliptic orbits a number of electrons equal to the atomic number of the element. The nucleus has practically the whole mass, and carries a positive electric charge, equal to the atomic



Hydrogen



Carbon

Models of atoms with electrons circling around the nucleus.

number, In this way the atom as a whole is electrically neutral, since it contains an equal number of positive and negative elementary electricity charges. The attraction between the positive nucleus and the negative electrons is just balanced by the centrifugal force of the electrons orbiting around the nucleus. The dimensions of this miniature planetary system are on an ultra-microscopic scale, the diameter of the orbits of the electrons being of the order of one-hundred millionth of a centimetre, whereas the diameter of the nucleus is about 20,000 times smaller.

We can easily understand now, how it is that when alpha or beta or gamma or X-rays pass through the air they easily knock off one or other of the electrons rotating around the atomic nuclei of the gas molecules in the air. The result of course is, on the one hand a positively charged particle, and on the other hand a negative particle, an electron, which very quickly settles on a neutral atom and so makes it negative. In this way the air is rapidly filled with positively and negatively charged particles, called ions, and although on recombination the ions lose their charges, new ones are constantly produced as long as the ionizing rays are active.

The Atomic Nucleus. This part of the atom requires closer scrutiny. As we have said, it contains practically all the mass of the atom and a number of positive elementary electric charges equal to the atomic number of the element. These positive charges are contributed by an equal number of protons being present in the nucleus, and the rest of the mass is made up by the neutrons, their number being equal to the difference between the atomic mass and the atomic number of the element. This means that a hydrogen atom, having atomic number 1 and atomic mass 1, consists of one proton as nucleus with one electron turning around it. A helium atom has a nucleus consisting of two protons and two neutrons, with two electrons turning around it. A uranium atom has a nucleus containing 92 protons and (238-92) neutrons with 92 electrons turning around it. You should note that in the lower range of atoms the number of protons and neutrons in the nucleus is almost equal, whereas higher up in the list of atoms the proportion of neutrons to protons in the nucleus gradually increases as is clearly seen in the case of uranium.

We understand now the meaning of isotopes, those twin atoms having the same atomic number and identical chemical properties but having different masses. It means that their nuclei have the same number of protons but different number of neutrons, and the number of electrons circulating around either of the nuclei are the same.

So far we have reasoned as if the atomic masses were all integer numbers, so that the different atoms could be built up by combining different numbers of protons and neutrons, with a number of electrons thrown in, but the total mass of the latter is always negligible. But the atomic masses of some atoms are far from being exact integers, such as chlorine: 35·5, iron: 55·8, silver: 107·88, etc. This difficulty is easily cleared when we remember the existence of isotopes, it means that when scientists, especially the chemists, determine the atomic mass of, say chlorine, they in fact determine the mass of different isotopes of chlorine of slightly different masses, mixed in such proportions that the result is one of the numbers as given above.

That this is not merely a clever way of evading the difficulty was definitely shown when scientists, this time the physicists, following the lead of J. J. Thomson, were able to devise experiments which in reality determined the masses of individual atoms. Such instruments are called mass-spectrographs, and they clearly showed that quite a large number of elements have two or more isotopes and that in nature these are always mixed in the same proportions so as to give the fractional number, when their mass is determined in bulk, as is done by the chemists.

Mass-Defect. Many more fundamental discoveries were made with these mass spectrographs, especially after they had been perfected and their measurements rendered more precise, so that with their help the atomic mass of an element could be determined with an accuracy of one in a hundred-thousand or even better.

Then the unexpected, and at first bewildering, discovery was made that, taking as the basis of calculations the mass of oxygen as 16, practically not a single atom has a mass which is expressed by an exact integer number, even when considering separately every isotope. Thus the mass of hydrogen was found to be 1·008, that of helium 4·004, that of potassium 39·10, that of uranium 238·07, etc. As a matter of fact all these quantities differ by only a very small fraction of a unit from an integer number, which is the quantity assigned to that element as its atomic mass, before such refined measurements were possible.

At first it would appear that we were quite wrong in assuming that the nucleus of an atom is built up by adding a few protons and neutrons in the proportions as explained above, since, taking the case of helium as an example, the sum of the masses of two protons and two neutrons is not equal to the mass of a helium atom. Yet, in a way, it was the discovery of this so-called mass defect (difference between the actual mass and the nearest integer number) which provided the basis for the research on the release of atomic energy. However, this had to be considered in the light of another fundamental statement that originated from the most eminent mathematician of our age, Albert Einstein.

Mass-Energy Relationship — Einstein's Formula: $E = mc^2$. Einstein achieved world renown by his famous theory of relativity, and his fame appears all the greater because his theories can be understood by only a very small fraction of humanity. In 1905, Einstein deduced a remarkable conclusion from his relativity theory, which established a definite and quantitative relation between matter and energy. He proved, as he put it, that 'the mass of a body is a measure of its energy content'. He established an exact equivalence between mass and energy which means that a definite quantity of mass can be transformed into another definite quantity of energy. The definite relation between m, the mass destroyed, or better, converted, and E, the energy released, is given by the equation $E=mc^2$, where c is the velocity of light expressed in centimetres per second (thirty thousand million cm. per sec.), m being expressed in grams and E in ergs, the units of work. To translate this famous equation into popular language, we might say that the energy released by the complete destruction, or better transformation, of a pound of matter is equivalent to that produced by the burning of one million tons of ordinary fuel. Hence the comparisons which have become so popular, such as that half a glass of water contains enough energy to drive a large ship across the Atlantic ocean and back. That means that if one were able to make all the water in the glass cease to be mass and in the process be converted into energy. This is precisely the crux of the problem: how to transform matter into energy.

The key to this mysterious Pandora's Box was provided by the spontaneous radio-active disintegrations constantly going on in nature. We have referred to the enormous amounts of energy being continuously emitted in the form of radiations and heat by the radio-active substances without any appreciable change in their condition, and we were at a loss to trace the origin of all this energy. Consider once again the disintegration process taking place simultaneously with this production of energy, and consider further the accurate masses of the original atom, say radium, and of the products of its disintegration, say, in this case, a radon atom and a helium nucleus, then you will find that the total mass of the radon atom and the helium nucleus is slightly less than the mass of the originally radium atom. Here then is the key to the mystery: a small quantity of matter has disappeared, and even this very small difference in the masses before and after disintegration, when multiplied by the square of the velocity of light expressed in centimetres per second, represents quite an appreciable amount of energy. This then is the origin of the energy possessed by the rays emitted in the process, as well as of the heat simultaneously released. Accurate numerical calculation of the amount of mass destroyed and the corresponding amount of energy released have fully confirmed Einstein's prediction as expressed in his famous equation $E=mc^2$.

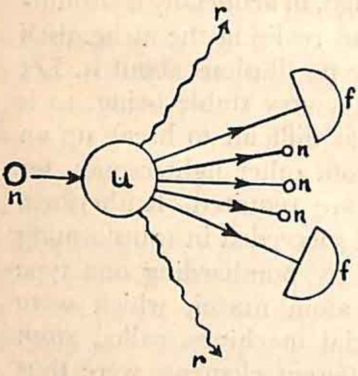
This is of course a momentous discovery. It now looks as if it were mere child's play to obtain enormous quantities of energy by transforming one type of atom into another provided that in the process there is a loss of mass. Let us, therefore, examine the list of the exact atomic masses of all the elements as determined by the scientists with the help of the mass-spectrographs. This list of atomic masses shows interesting facts at both ends of the list. Starting from the far end, we find that the masses of the heavy elements are such that if they break up into two or more lighter elements there will be a loss of mass. At the lower end it is just the reverse, for instance if two protons and two neutrons could be so perfectly joined that they form one helium nucleus there would be a loss of mass, and this is the case with quite a few of the lighter elements, when building up a heavier element out of a few lighter ones. Therefore two processes are available for releasing enormous amounts of energy in accordance with Einstein's formula, either by breaking down heavy elements into lighter ones, or by building up, or fusing, very light elements into slightly heavier ones. The first process of energy release by breaking down is, as we have seen, taking place continuously and spontaneously in nature in the case of radio-active disintegrations. The other process of energy release by building up, or fusing, lighter elements is also continuously going on in nature. Scientists tell us that this is the way in which the sun and other stars manage to maintain their enormously high temperatures in spite of the vast quantities of heat which they have been continuously radiating into space for several thousand million years. Thus in the case of the sun, whose temperature at the centre is over 20 million degrees Centigrade, its enormous supply of heat is derived from the continuous fusion of hydrogen atoms into helium atoms which takes place quite spontaneously at the high temperatures prevailing at the centre.

Artificial Release of Atomic Energy. Can we imitate nature in this wonderful process of producing energy by the destruction of mass resulting from the breaking down or the building up of one type of atoms or another?

On the theoretical side, Rutherford and his collaborators were once again in the vanguard of this enthralling quest. They succeeded, quite some time ago, in artificially transmuting one element into another, thus realising the alchemist's dream. However, we should have no illusions about it. Let us not forget that every atom is a very stable being, as is suggested by its name. It is just as difficult to break up an atom as to build up an atom from other lighter ones, for either process enormous forces are required. Rutherford, and many after him, have indeed succeeded in transforming one type of atoms into another by bombarding one type of atoms with other atoms or atom nuclei, which were given great accelerations in special machines, called atom smashers. Quite a number of different elements were thus transformed into other elements, and in the process the loss of mass was converted into energy, called atomic energy. Unfortunately these were not paying concerns because for every successful hit in this atomic bombardment there were several million duds, so that on the balance much more energy was spent in firing these millions of particles than was derived from the relatively few successful transformations. However, the principle had been firmly established that man can by his own means transform one element into another with a corresponding loss of mass and release of what we call atomic energy.

Atomic Fission. The experiments on atomic bombardment continued on an ever expanding scale, in particular as regards the energy with which the atomic projectiles were hurled at the atomic targets, because it was realised that the greater the striking force the greater were the chances of a lucky hit.

In 1938 a new phenomenon in this line was announced by a German scientist, O. Hahn. He had discovered that while bombarding uranium atoms with neutrons, instead of a small chip being knocked off the uranium atom, the neutron at first penetrated into the uranium and then produced an explosion, the uranium splitting up into almost two equal parts, hence the name of uranium fission. But this was not all. In the explosion of the uranium atom along with the ejection of two rather heavy particles, some two or three fast travelling neutrons were simultaneously ejected along with a large amount of powerful radiations.

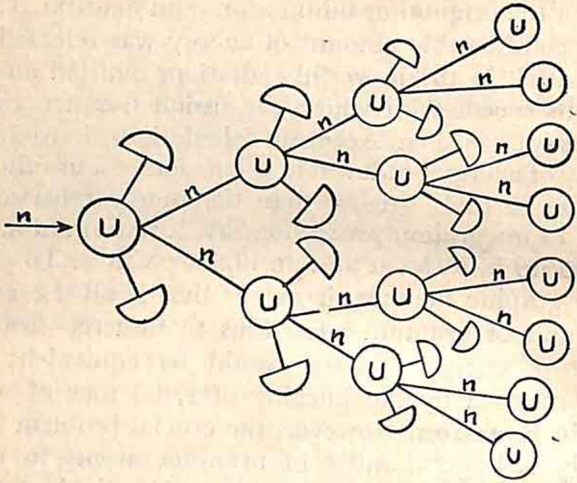


Fission of uranium atom.
f, fission fragments;
n, neutron; u, uranium;
r, radiation.

The sum total of the masses of all the particles into which the original atom broke up was quite a bit smaller than the masses of the original uranium atom and neutron. Therefore quite a considerable amount of energy was released, which showed itself in the powerful radiations emitted and in the enormous speeds with which the fission fragments and the neutrons were ejected. Accurate calculations showed that the quantity of energy produced in the fission of a uranium atom was some 20 times greater than the energy released in the natural disintegration process of, say, a radium atom, when it breaks up into radon and an alpha particle. To put it in a more graphic manner, it means that if all the atoms in one pound of uranium were thus to undergo fission, the amount of energy released would be equivalent to the energy released by the burning of 1,400 tons of coal.

Chain Reaction. However, the crucial problem is to get precisely a large number of uranium atoms to undergo fission in a very short time, because each individual uranium fission releases only a microscopic amount of energy. Here we come to the most important point in the uranium fission, and it is that, together with the release of energy, there is an ejection of two or three high speed neutrons. Now these fast travelling neutrons may in their turn penetrate into some of the neighbouring uranium atoms and set off another explosion with the release of energy and some further neutrons which can produce further fissions and so on. It means that we have here all the elements for a chain reaction which will spread over an ever expanding range, because every fission produced by one neutron will eject two or three neutrons which in turn may trigger off new fissions, and so on.

This is all the more striking when we learn from the scientists that the time interval between two such successive fissions in a chain reaction is less than one-hundred-millionth of a second, which means that starting with one fission, then two, then four, eight, etc., we have to multiply each successive number by two and do this one-hundred-



Uncontrolled chain reaction.

million times before reaching one second. This comes to a far larger number of atoms than those contained in one pound of uranium. Therefore, if a chain reaction, as explained above, could take place, in one second much more energy would be released than in the burning of many thousands of tons of coal. The production of such an enormous amount of energy in a fraction of a second would naturally result in a tremendously violent explosion.

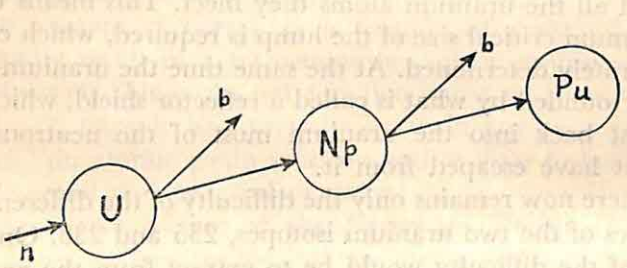
However, things do not function quite as simply as all that, and happily so, otherwise it would not be possible to control an atomic chain reaction with a view to harnessing it for useful and peaceful purposes.

The Mannerisms of the Uranium Twins, 235 and 238. You may remember that we have mentioned that uranium has three isotopes, the two important ones having masses 235 and 238, the latter being far more abundant in the ordinary uranium as extracted from the ores; in fact for every uranium 235 there are 140 uranium 238. The fission process just explained takes place only when a neutron penetrates into a uranium 235, therefore even when we have to deal with ordinary pure uranium, the chance of a fission is only one in 140, and as every fission releases only 2 or 3 neutrons, there is hardly any chance of a chain reaction being started.

There are still other troubles. We have assumed so far that every neutron, released in the event of a fission, will enter another uranium atom, 235 or 238, but we must consider some of the tiny swift neutrons slipping between the rows of uranium atoms and finally escaping from the lump of uranium out into the surrounding air. And we must also consider some of the neutrons entering into some of the impurities which are always present, at least in small amounts even in the most purified uranium lumps. There are thus quite a number of formidable obstacles to be overcome to get a chain reaction going.

First of all we have to prepare a quantity of uranium as pure as possible to minimise the loss of neutrons through absorption by impurities. To prevent as far as possible the neutrons from escaping out of the uranium lump, we must take a sufficiently large lump, so that there is very little chance that the neutrons on their way out will be able to avoid all the uranium atoms they meet. This means that a minimum critical size of the lump is required, which can be accurately determined. At the same time the uranium lump is surrounded by what is called a reflector shield, which will reflect back into the uranium most of the neutrons that might have escaped from it.

There now remains only the difficulty of the different properties of the two uranium isotopes, 235 and 238. One way out of the difficulty would be to extract from the ordinary mixture of the two isotopes all the isotopes of one kind, so that we would have a lump of almost pure uranium 235, and if the lump reaches the minimum size, in fact as soon as it reaches this size, we would get a successful chain reaction, resulting immediately in a terrific explosion. This in fact is the principle of the atom bomb. However, to separate these twin uranium atoms is not an easy task, since all their chemical properties are identical, therefore no chemical methods of separation will work and the methods used are to be based on the fact that the two have slightly different masses. This is a slow and extremely costly process, especially when rather large quantities are needed. Luckily there is another way of getting round the difficulty, more workable and less expensive, which is based on the different ways in which the neutrons act on the two different types of uranium. It was found that neutrons moving at very high speed enter readily both types of atoms, but neutrons of medium speed penetrate rather easily into uranium 238 but not into uranium 235, whereas in the case of neutrons of relatively slow speed it is just the reverse. Another very interesting fact is that when neutrons penetrate a uranium 238 atom it does not split up into two, but it keeps the neutron and emits a beta particle. This is equivalent to the atomic number of the particle changing from 92 to 93, and in fact a new element is thus produced, which was given the name Neptunium. This element itself is not very stable and in its turn gives off another

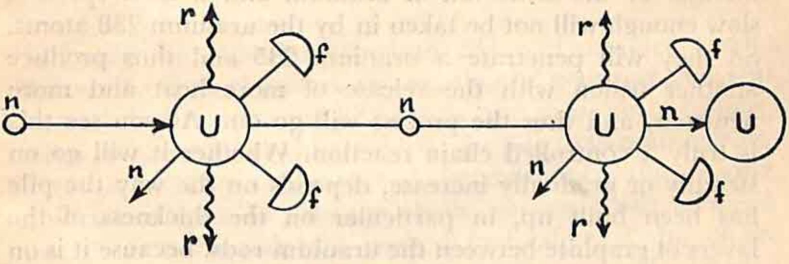


Transformation of uranium 238 (U) into Neptunium (Np) and Plūtonium (Pu); b, beta ray; n, neutron.

beta particle thereby raising its atomic number to 94, which means a new element and this one was called Plutonium. Studying the properties of this newly created element plutonium, it was found to behave exactly like uranium 235, which means that when a neutron penetrates a plutonium atom it results in a fission with release of much energy and a few high speed neutrons.

The problem then was to act on the high speed neutrons emitted in a fission so as to slow down their speed. This can be done by making these neutrons, ejected from the splitting uranium atom, move through certain light substances where the neutrons repeatedly collide with some of the atoms of this substance without being absorbed by them, and so gradually lose some of their energy and speed. It was found that substances rich in hydrogen, or heavy hydrogen (heavy water), or carbon (graphite) were very suitable for this purpose.

Atomic Reactors. Controlled Chain Reactions. Applying the above principle it is now possible to set off a chain reaction of uranium fissions that will either gradually increase

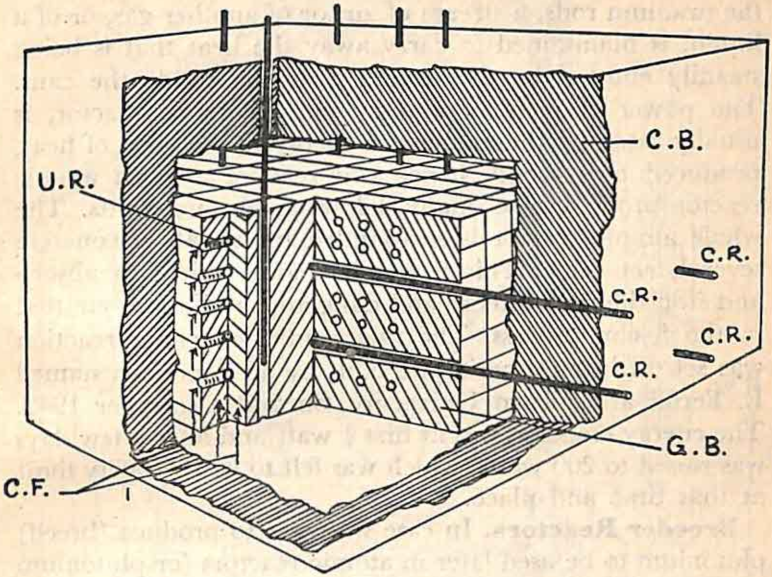


Controlled chain reaction.

and spread out fanwise or be maintained at a steady pace and with a steady production of energy. It all depends on whether, of the neutrons emitted in every given fission, just one neutron, or more than one neutron (albeit only a small fraction more than one) will penetrate into another uranium 235 and produce another fission and so on.

At first a given quantity of ordinary uranium is taken so as to reach the minimum critical size. This then is divided into a large number of small lumps, usually in the shape of long narrow rods enclosed in a thin casing of magnesium or stainless steel; a large number of blocks of graphite are also brought in. Then we start building an 'atomic pile', by piling up the graphite blocks in regular layers with here and there between the blocks a tube of uranium, so that the uranium rods are at equal distances from each other and separated by layers of graphite.

You should know that all the time there are some neutrons moving about in the air all around us. Therefore now and then, a neutron will enter a uranium 235 in one of the rods and produce a fission with the emission of heat and a few high speed neutrons. These neutrons will easily escape from the narrow uranium rod and will then wander among the carbon atoms of the graphite, gradually losing speed due to a series of collisions; eventually they will meet another or the same rod of uranium and if their speed is slow enough will not be taken in by the uranium 238 atoms. So they will penetrate a uranium 235 and thus produce another fission with the release of more heat and more neutrons, and thus the process will go on. As you see this is truly a controlled chain reaction. Whether it will go on steadily or gradually increase, depends on the way the pile has been built up, in particular on the thickness of the layers of graphite between the uranium rods, because it is on this that it depends how many neutrons will have their speed sufficiently slowed down for them to enter a uranium 235 and not the other isotope. Of course, the size of the pile also matters, because on it depends whether a certain number of neutrons will escape or not, and so whether on an average one or more neutrons resulting from one fission



Model of atomic pile.
C.B., concerete blocks for shielding; C.F., cooling fluid to fuel channels; C.R., control rods; G.B., graphite blocks; U.R., uranium rods.

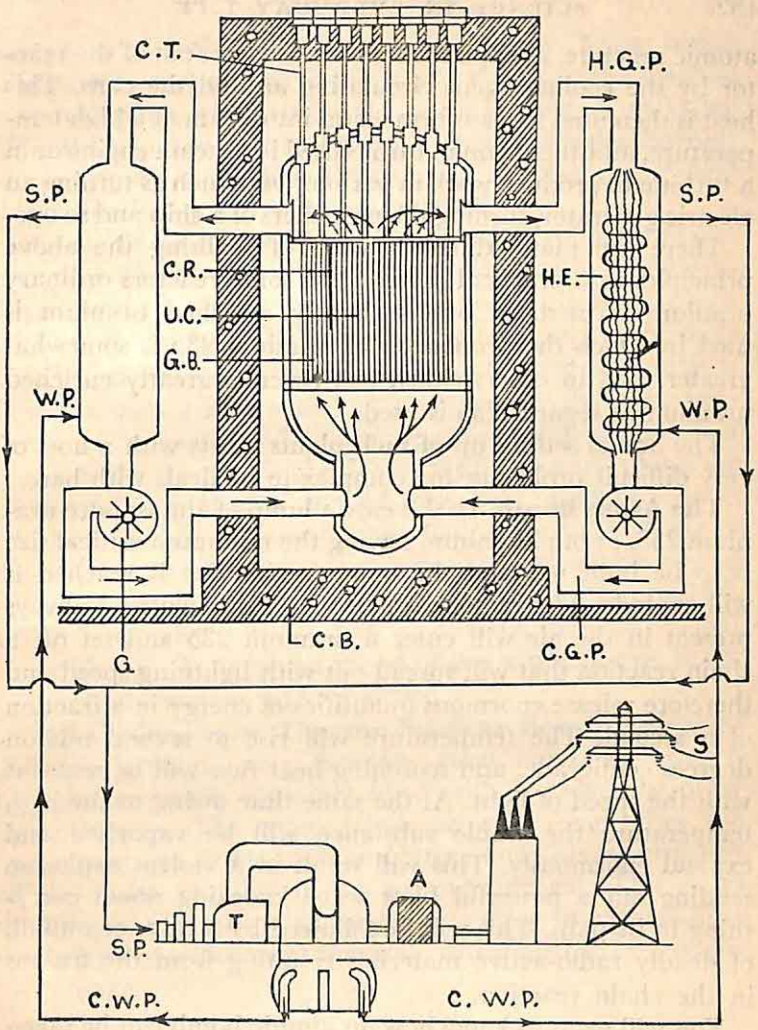
will enter into another uranium 235 and produce a new fission. To control further the number of neutrons that will be absorbed by uranium 235 atoms, and so produce fissions, a few control rods are inserted into the pile to various depths. These are rods of cadmium or other substances that readily absorb neutrons. In case the chain reaction tends to speed up too fast the rods are pushed in further, if the chain reaction tends to slow down, the rods are pulled out a little. These rods therefore act as breaks for the chain reaction, their movements are regulated by an automatic control mechanism.

In between the graphite blocks, along the cans encasing the uranium rods, a stream of air, or of another gas, or of a liquid, is maintained to carry away the heat that is being steadily emitted by the fissions going on inside the cans. The power of such an atomic pile or atomic reactor, is usually rated by the amount of energy in the form of heat, produced per second, hence you read of a given atomic reactor producing so many kilowatts or megawatts. The whole atomic reactor is surrounded by a wall of concrete several feet thick. This is the biological shield to absorb and stop the very intense and dangerous radiations emitted in the fission process. The first controlled chain reaction was set off in an atomic pile built by an American named E. Fermi at Chicago University, on 2nd December 1942. The energy emission was at first ½ watt and after a few days was raised to 200 watts, which was felt to be the safety limit at that time and place.

Breeder Reactors. In case we want to produce (breed) plutonium to be used later in atomic reactors (or plutonium atom bombs), the above arrangement of the atomic pile is to be modified so that a certain proportion of the neutrons produced enter uranium 238 atoms which will thus be gradually transmuted into neptunium and then plutonium.

That means that the thickness of the layers of graphite between the uranium cans must be less, so that the neutrons do not wander so long amongst the carbon atoms before re-entering a uranium can. In this way we shall have a mixture of neutrons of different speeds, some of which being slow enough will enter uranium 235 atoms and produce fission and emit new neutrons to keep up the chain reaction. Some other neutrons, being faster, will enter uranium 238 atoms and produce plutonium. All this of course requires quite a lot of delicate adjustments and plenty of preliminary study and calculations.

Atomic Energy for Peaceful Purposes. The heat released as the result of the controlled chain reaction in the



An atomic energy plant for producing electricity.
A, alternator; C.B., concrete block for shielding; C.G.P., cool gas pipe; C.R., control rod; C.T., charge tubes; C.W.P., cool water pipe; G, gas blower; G.B., graphite blocks; H.E., heat exchanger; H.G.P., hot gas pipe; S, electric supply to town; T, turbine; S.P., steam pipe; U.C., uranium cans; W.P., water pipe.

atomic reactors, as explained above, is taken out of the reactor by the cooling agent circulating around the cans. This heat is then used to transform water into steam at a high temperature, and the steam in turn is used in a steam engine or in a turbine to produce work in various ways such as turning an electric generator, turning the propellers of a ship and so on.

There are many different ways of realising the above principles in a practical manner. In some reactors ordinary uranium is used, in others slightly enriched uranium is used in which the proportion of uranium 235 is somewhat greater, and in others called fast reactors greatly enriched uranium as regards 235 is used.

The actual setting up of such plants meets with a host of very difficult problems, too complex to be dealt with here.

The Atom Bomb. In this case a lump of almost pure uranium 235, or of plutonium, having the minimum critical size is to be built up, and the moment this size is reached it will explode. The reason is that one of the neutrons always present in the air will enter a uranium 235 and set off a chain reaction that will spread out with lightning speed and therefore release enormous quantities of energy in a fraction of a second. The temperature will rise to several million degrees centigrade, and scorching heat rays will be sent out with the speed of light. At the same time owing to the high temperature the whole substance will be vaporised and expand enormously. This will result in a violent explosion sending out a powerful blast wave knocking down everything in its path. This will be followed by a rain, or outfall, of deadly radio-active materials resulting from the fissions in the chain reaction.

You will want to know how an atomic bomb can be taken to the place where it is meant to explode, since as soon as it is assembled it explodes spontaneously? The solution consists in building up two or more lumps of uranium 235 or plutonium, each of them below the critical size, but the aggregate of them reaching the critical size. These lumps being kept apart are taken to the place where the explosion is to take place, then an automatic mechanism is triggered off at the required time and place, which pushes the different lumps rapidly and violently together so that the critical size is reached and the bomb goes off.

Power from Atomic Fusion. We have explained how in the sun enormous amounts of energy are continuously produced by the building up of helium from hydrogen, which entails a loss of mass. This goes on spontaneously in the sun's core because of the enormous temperatures prevailing there. Our scientists are now trying to realise equally high temperatures, say many millions of degrees centigrade, inside a gas of hydrogen or of other very light elements. Once the fusion reaction is thus started, the heat produced by it will be sufficient to keep the reaction going with plenty of energy to spare for useful purposes. The great problem, of course, is how to reach such an initial high temperature and, which is equally difficult, how to arrange matters so that everything in the neighbourhood of this artificial sun, is not immediately melted and vaporised.

The Hydrogen or Thermo-Nuclear Bomb. This is an ordinary uranium or plutonium atom bomb surrounded by a larger strong container filled with hydrogen or other light element. The atom bomb on exploding raises the temperature to a few million degrees and this in turn sets off the fusion reaction in the surrounding gas. This raises the temperature still much higher, resulting in an explosion the energy of which is of the same order as that of a major earthquake.

CHAPTER ACTIVITIES

Outdoors

Visit an industrial museum and examine the exhibits on atomic energy.

For your wall newspaper

Mount cuttings from newspapers and magazines that deal with atomic energy.

Note-book exercise

Make notes from newspapers and popular science journals about atomic nuclear plants and their various applications for peaceful purposes.

At home

If you have a watch with a luminous dial you can perform the following experiment. At night, take a powerful magnifying glass and switch off the light. After your eyes have become accustomed to the dark, look at the dial through the magnifying glass. You will see a luminous glow moving continuously from one spot to another, like a moving glow-worm. What you actually observe is the phosphorescent substance in the dial becoming luminous at the various spots hit by the alpha particles emitted by the few grains of radio-active substance behind it.

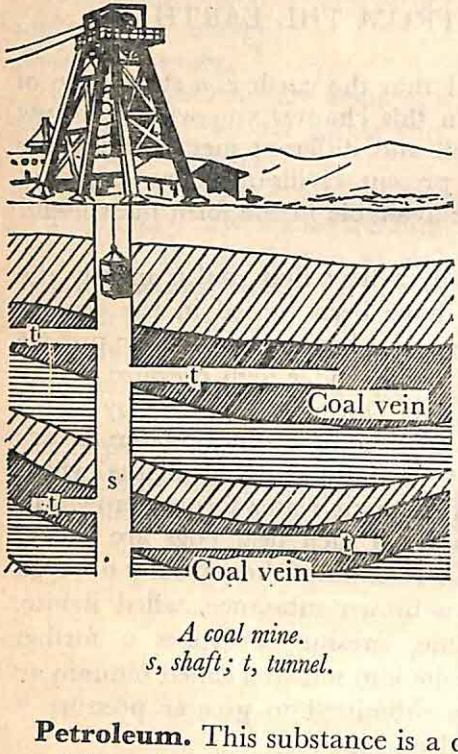
CHAPTER VI

MINERALS FROM THE EARTH

You have read in Book I that the earth is a storehouse of many types of wealth. In this chapter you will read how materials such as coal, oil and different metals which are daily necessities in our present civilisation are extracted from the earth and made available in the form most useful to us in our daily life.

Coal. Scientists generally believe that coal is merely the remains of plants which have been buried in the ground many millions of years ago and have reached their present condition as the result of being under high pressure by the soil and rocks that lie above. During the process by which plants are changed to coal, four distinct materials are formed. The remains of partially decayed plants which pile up at the bottom of stagnant water form a brownish-black substance called peat. If such peat bogs are deeply buried under sediment the remains of the partially decayed plants slowly change to a brown substance called lignite. After a considerable time, pressure provokes a further change of some of the lignite into soft coal called bituminous coal. When such coal is submitted to greater pressure it becomes hard coal called anthracite.

Coal is chiefly mined in two ways, If the layers of coal are found just beneath a shallow layer of soil it is obtained by stripping off the top layers with large shovels so that the coal can then be dug out of the earth. This method of mining is called strip mining. If the coal lies at a considerable depth below the surface of the earth in seams, deep holes, called shafts, are sunk in order to reach the seams. Tunnels are dug sideways which extend from the shaft to the seams. The roofs of these tunnels are supported by wooden or iron pillars. Coal is extracted from the seam by tools such as pick-axes or electrically driven cutters or by the use of explosives. The coal within is taken to the shaft either by little wagons running on rails or by conveyor belts. It is then hauled to the surface in cages. This method of obtaining coal is called shaft mining. Besides the main shaft for the removal of coal there is another shaft to help in the ventilation of the mine. Fans are used to suck the stale air up one shaft and blow fresh air down the other shaft. In this way fresh air is supplied to the men working in the mine.

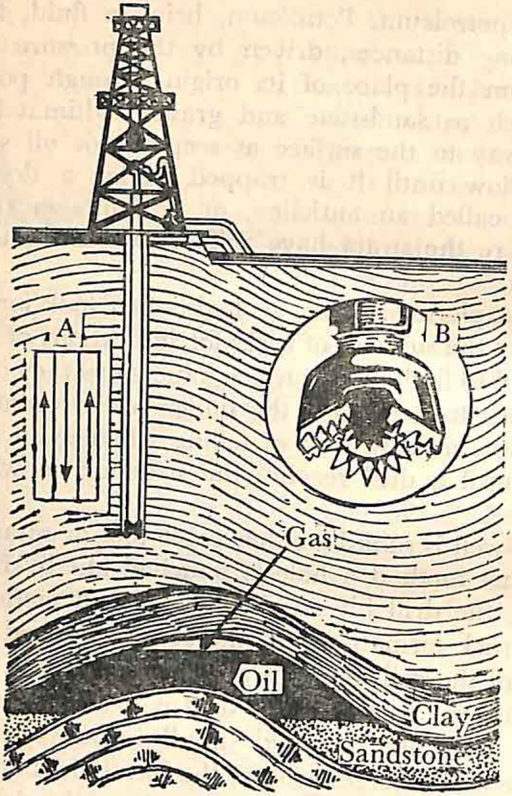


A coal mine.
s, shaft; t, tunnel.

Petroleum. This substance is a dark-coloured oily liquid consisting of a mixture of many substances. Gasoline, kerosene oil, fuel oils, lubricating oils, paraffin, asphalt and solvents for paints, are just a few of the many important substances obtained from petroleum. Scientists generally believe that petroleum is derived from the remains of marine organisms which were trapped in the mud of primaeval seas and inland lakes millions of years ago. The remains of these organisms, both plants and animals, gradually built up an ooze which was covered by silt and sand, and over many centuries was finally converted by geologic forces to petroleum. Petroleum, being a fluid, flows, and travels long distances, driven by the pressure of gas or water from the place of its origin through porous rock strata such as sandstone and gravel. Ultimately it may find its way to the surface as seepages or oil springs, or it may flow until it is trapped under a dome-shaped structure called an anticline, or at faults in the earth's crust where the strata have shifted to seal off the porous formation.

When exploring for oil, geologists first look for seepages, then study the surfaces of rocks for indications of anticlines. If they fail to find oil by surface indications they use various instruments to determine the underground geology. There is, however, no sure way of telling whether oil is actually present until a drill reaches the structure in which oil is trapped.

An oil well is sunk by either cable tool or rotary drilling. In the first method a hole is punched out by raising and dropping the drill bit on a cable. Such a method is used in hard rock formations. In the second method the bit at the end of the drill revolves at a great rate and thus bores a hole into the earth. As the drill is twisted down into the earth, a specially prepared 'mud' is pumped down the drill pipe and emerges around the bit. This is done to flush out rock cuttings to the surface, to keep the drill cool and also to cover the sides of the hole to prevent cave-ins. In both methods, a shell pipe which serves as a casing is lowered into the hole as the drilling proceeds. This is done to further lessen the chances of a cave-in. Once the oil-bearing material is finally reached, a smaller pipe is lowered into the well and sealed to the casing at the top so that the oil can only come to the surface through this small pipe. The depth of an oil well is usually between half a mile and two miles. The driving force which pushes the oil out of the earth is either the pressure of underground gas above the oil or



An oil well.
A, section of drill pipe.
Arrow pointing downwards shows the direction in which mud is pumped.
Arrows pointing upwards show the direction in which rock cuttings are flushed out.
B, drill bit.

the pressure of water situated below the oil. Very often, however, oil must be pumped up to the surface.

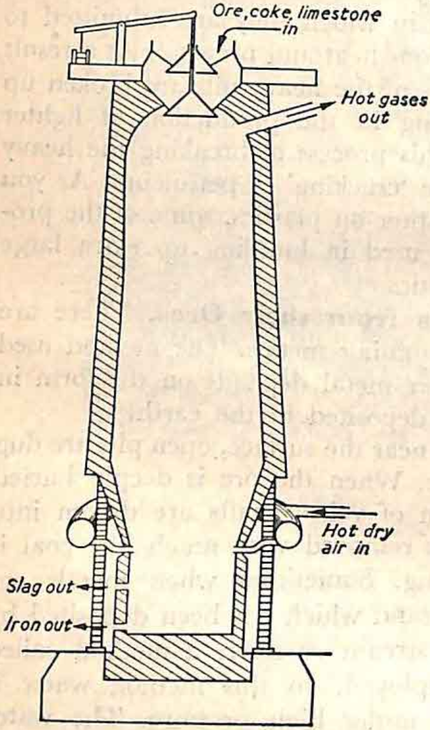
Refining and Processing of Petroleum. The crude oil obtained is taken from the oil well to the oil refineries, where the different constituents of the oil are separated by what is called fractional distillation. This means that the oil is being gradually heated and as the different constituents have different boiling points, each of them in turn comes out of the mixture at its boiling temperature and is then gathered in a different recipient. In this way the various products are separated, from the very volatile products like gasoline to the heavy oils and tar.

In order to obtain more oils of the lighter type that can be used as fuel, some of the heavier oils are then taken through a special process in which they are submitted to a combination of tremendous heat and pressure. As a result of this the large molecules of the heavy oils are broken up into smaller ones resulting in the production of lighter products, like gasoline: this process of breaking the heavy oil molecules is called the 'cracking' of petroleum. As you will read later in the chapter on plastics, some of the products of oil refining are used in building up extra large molecules to produce plastics.

Extraction of Metals from their Ores. There are several methods used in mining metals. The method used in the case of a particular metal depends on the form in which the ore has been deposited in the earth.

When the ore lies at or near the surface, open pits are dug into the body of the ore. When the ore is deeply buried in the earth in the form of veins, shafts are driven into the earth and the ore is removed very much like coal is removed by shaft mining. Sometimes when metals are contained in gravel and sand which has been deposited by an existing or dried-up stream or river, a method called hydraulic mining is employed. In this method water is pumped into the earth under high pressure. The water loosens the sand and gravel which are then washed with water. Once the heavy metal settles at the bottom it is easily collected. The method used to extract a particular metal from its ore depends upon the elements with which it is combined in the ore. Most metals are found combined in the form of an oxide. Such an ore is called an oxide ore.

Iron. This metal is generally obtained from an oxide ore. The ore is mixed with coal or coke and limestone and the mixture is charged into a blast furnace. This apparatus is a shaft of steel lined inside with firebrick. It is between 50 and 100 feet high and about 25 feet in diameter. There are air jets at the base of the furnace through which a blast of pre-heated air enters. As a result of the chemical action going on, the mixture inside the blast furnace is heated to a high temperature by a process called smelting. The coke, by combining with the oxygen of the iron oxide, serves to separate the iron from the oxygen while the limestone combined with the earthy matter in the roasted ore to form a liquid called slag. The molten iron settles to the bottom of the furnace and accumulates in the crucible at the bottom while the slag floats on top of the metal. The molten iron is then separated from the slag and drawn off into moulds



A blast furnace.
Shaded portion represents firebrick.

where it hardens into blocks or bars known as 'pigs'. A blast furnace runs continuously for years, by continuous reloading at the top, and tapping the iron at the bottom. It is usually shut down only when the firebrick lining wears out and needs to be replaced.

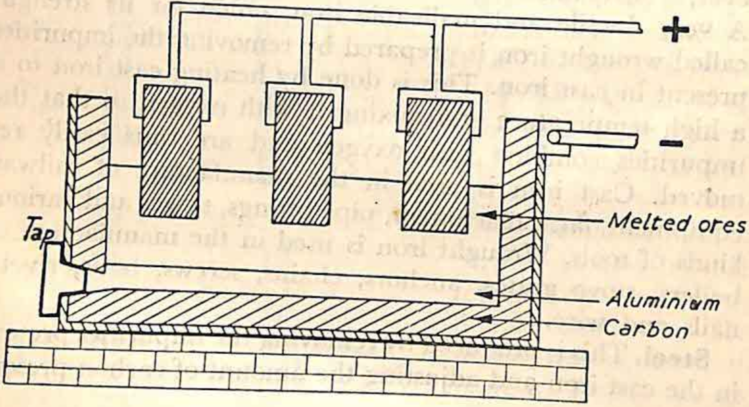
Pig-iron, the product of the blast furnace, is of little use since it is not malleable. A relatively small amount of it is generally converted into cast iron while most of it is converted into steel. If the conversion of pig-iron to cast iron is desired, the pig-iron is first melted and then poured into a sand mould of the shape desired. As it hardens the mould is removed. A malleable cast iron is produced by heating the pig-iron in the mould to a temperature of about 1,350°F, allowing it to remain at this temperature for about three days and thereafter cooling it slowly. Cast iron, however, is fairly brittle because of the impurities contained in it. A very ductile and malleable iron, noted for its strength called wrought iron is prepared by removing the impurities present in cast iron. This is done by heating cast iron to a a high temperature and mixing it with oxygen so that the impurities combine with oxygen and are thus easily removed. Cast iron is used in the manufacture of railway equipment, farm machinery, pipe fittings, stoves and various kinds of tools. Wrought iron is used in the manufacture of boilers, stove grates, anchors, chains, screws, bolts, rivets, nails and wire.

Steel. This is produced by removing the impurities present in the cast iron and adjusting the amount of carbon present in it.

There are different methods of removing the impurities present in the cast iron, the main principle being that impurities are removed by oxidation and subsequent slag formation.

In the Bessemer process this is brought about by a powerful blast of air passing through the molten cast iron, together with a series of reactions provoked by some other materials added to it. The carbon, if necessary, is added in one form or another; however, it does not chemically combine with the iron, but forms an alloy, called steel, about which you will read more in the next chapter.

Aluminium. It is difficult to remove certain metals such as aluminium from their ores by smelting, so another method, electrolysis, is employed. Although many silicate rocks and all the various kinds of clays contain aluminium, the only important ore from which the metal can be easily extracted is bauxite. The ore is treated with chemicals to form an oxide called alumina. This substance is dissolved in a mineral called cryolite which serves as the solvent and is then kept in a molten state at a temperature of about 1,000°C in an electrolytic cell. This cell consists of a steel shell



Extraction of aluminium by electricity.

lined with carbon. The carbon lining is connected to the negative terminal of a source of electricity and therefore serves as the cathode. Large carbon rods dipping into the solution are connected to the positive terminal and therefore serve as the anode. On passing a current of electricity through the solution enough heat is generated to keep the cryolite molten. From time to time alumina is added. Oxygen is given off from the anode which gradually burns away, while molten aluminium collects at the carbon lining. Periodically, the aluminium metal is drawn off into moulds and hardens as cast aluminium.

The uses made of aluminium depend on its properties. Since it is very light and elastic it is drawn into wires and rolled into thin sheets. Since pure aluminium has a rather low tensile strength, a steel core is added to the aluminium wire to give it the necessary strength. Such wires are used for electric power cables. Sheets of aluminium are used in the construction of the framework of aeroplanes. When aluminium is exposed to air it gets covered with an extremely thin invisible film of oxide which adheres to the surface and protects it from further chemical action. Since this coating of oxide does not diminish its lustre, the metal is used as a reflector of radiant energy. Aluminium has excellent heat conductivity and this property makes it useful for cooking utensils.

Copper. You have read of oxide ores. Certain metals such as copper are found combined with sulphur and the ore is called a sulphide ore. Copper is obtained from such ores by carefully controlled oxidation in the presence of silica. The ore is crushed to powder, washed to free it from earthy matter and then roasted, that is, heated in a good supply of air. The roasting is done in a shaft-like furnace in which scrapers stir the powdered ore, gradually moving it downwards from shelf to shelf in the furnace. During the process certain impurities are driven off, iron sulphide present in the ore is converted to iron oxide, while copper remains as copper sulphide.

The roasted ore is then smelted. This is done in a reverberatory furnace which reflects heat downwards from a dome-shaped roof. During this process sand, silica, and sometimes limestone, are added as a flux to combine with the iron oxide. The slag which now forms is removed. The copper remaining is still in the form of copper sulphide and there are also small amounts of iron sulphide remaining. This impure form of copper is known as matte.

The melted copper matte is then transferred to a converter. Here a blast of air converts iron sulphide to its oxide. Sand and silica are added to combine with iron oxide and the resulting slag is poured off. Some of the copper sulphide is now converted to copper oxide which reacts with the remaining copper sulphide to form metallic copper. As the molten copper cools, bubbles of sulphur dioxide produce 'blisters' in the copper. The metal in this state is called 'blister copper'. Finally, blister copper is taken for refining by electrolysis. The electrolytic cell is lined with lead and filled with a solution of copper sulphate and sulphuric acid. Sheets of blister copper are connected to the positive terminal of a source of electricity and thus serve as the anode. Sheets of pure copper of the same size as the impure sheets, but only of about $\frac{1}{16}$ to $\frac{1}{32}$ of an inch thick are connected to the negative terminal and serve as the cathode. On passing a current of electricity through the solution, copper is transferred from the impure sheets and deposited on the pure sheets while impurities fall to the bottom of the cell.

Since copper is ductile and malleable, and moreover, a good conductor of heat and electricity, it is used by the electrical industry as wire-cables, bars and other electrical conductors. The metal is also used to manufacture boilers, sheeting and many other articles where resistance to corrosion, strength and flexibility are important factors.

Zinc. The principal ore from which zinc is extracted is zinc sulphide. The ore is first finely ground. It is then converted to zinc oxide by roasting. Zinc oxide is first bleached with sulphuric acid and converted to zinc sulphate. This is then treated with zinc dust to remove all the less active metal impurities. After the deposited metal has been removed by filtration, the slightly acidified solution which remains serves as the electrolyte. A lead-silver alloy serves as the anode while a pure aluminium sheet plated with zinc serves as the cathode. On passing a current of electricity through the solution, metallic zinc is stripped from the cathode sheet. Thereafter, the zinc is remelted and cast into whatever form it is required.

Zinc is chiefly used in the manufacture of galvanised iron and in the making of brass.

Lead. Lead ores have many impurities in them and it is difficult to separate the pure metal. The chief ore from which lead is obtained is an ore containing lead sulphide, called galena. The ore is first washed with excess of air to convert part of the sulphide to oxide and sulphate. After roasting at about 800°C., the products are charged into a small blast furnace with limestone and coke and the crude lead produced is thereafter further refined.

Because lead is chemically inactive and consequently resists corrosion and chemical attack, it is used in the manufacture of plates for storage batteries, for pipes meant for the conduction of corrosive chemicals and for making sheets for lining sinks, vats and other surfaces which come into contact with chemicals.

Tin. The principal ore from which tin is obtained is an oxide called cassiterite. The ore is first roasted. During this process the sulphides of foreign metals are converted to oxides and volatilised, The resulting tin oxide is then heated either in a blast or reverberatory furnace. The product, metallic tin, is then heated on a sloping hearth. Since pure tin has a low melting point it melts first and flows off, leaving the impurities behind. Electrolysis is also used to refine tin.

Tin is chiefly used to manufacture tin plate for 'tin' cans.

Silver. Silver is obtained from various ores in which there are small amounts of the metal. Agents, called collectors, such as mercury, zinc, copper matte, a solution of potassium or sodium cyanide, sodium thiosulphate and sodium chloride, are used to dissolve silver from its ore. It is then obtained from these solutions by various chemical means.

Silver is chiefly used for coinage and for making ornaments.

Gold. Gold is one of the metals that are found in nature in the metallic state. When found in reefs or veins of quartz, the quartz containing the metal is crushed and the metal is then separated, usually by washing away the lighter quartz or by chemical means. Gold is sometimes found deposited in river beds in the form of fine grains called gold dust.

Gold is one of the most valuable of metals. It is used as currency and for making ornaments.

CHAPTER ACTIVITIES

Outdoors

1. Visit a mine, also a factory in which metals are extracted from their ores.
2. Collect samples of various metals and also specimens of different kinds of ores.

For your wall newspaper

On a sketch map of India, indicate where the minerals mentioned in this chapter are to be found.

Note-book exercise

Write an account of the mineral wealth of your state.

At home

Make a list of the various metals that are to be found in your house. Beside each, write what use is being made of it.

CHAPTER VII

SYNTHETIC MATERIALS

THE age of jet engines, of atomic energy, and of all sorts of complex products coming out of chemical factories, would not be possible were it not for the abundance and variety of metals and their numerous alloys. They provide the structural engineer with the particular material required for a definite purpose. In case new needs arise the metallurgists will set about to discover new alloys, by mixing two or more different metals in various proportions until an alloy is produced which complies with the definite specifications for a particular job. Naturally all this is not done in a haphazard manner, a large amount of information on the subject has been gathered, classified and synthesised into a system of rules and principles that guide the metallurgists in their further quest for new and special alloys.

ALLOYS

Metals and Alloys. Metals are used for tools, and for structures of all types, because of their special properties. Metals are hard and tough, and at the same time have elasticity, yielding a little under the stress without breaking or without permanent deformation. Metals are rather easily worked, they are ductile and malleable, they can be shaped into various forms by bending and hammering, or by pouring the molten metal into moulds. Metals are also durable because they can resist the disintegrating action of agents such as water, gases and other chemicals. Metals are heat-resistant and keep their strength even when hot.

From ancient times people have been using metals first for making primitive tools, then more elaborate utensils and ornaments. Up to rather recent times only some seven common metals were readily available, they were iron, copper, zinc, tin, lead, silver and gold. These metals were used for different purposes according to the special properties of each of them, some being specially tough, others more elastic, others more plastic, others more heat- or water-resistant, etc.

With the primitive methods of extraction in use it was of course not possible to obtain very pure metals, and this proved to be a blessing in disguise. From very early times it was found that metals containing certain impurities possessed greatly improved qualities. So the idea gradually developed of mixing the various metals by melting together various proportions of two or even more different metals. In this way new types of metals were discovered, which are called alloys. The two or more metals melted together do not form new chemical combinations: they retain their respective identities but are very intimately mixed and when the right metals are mixed in the right proportions some very useful alloys are produced.

The most ancient example of such an alloy is bronze, which is copper with a little addition of tin. This alloy was in use in very ancient, even prehistoric times, the civilisation of the Bronze age coming immediately after that of the Stone age, and then followed by the Iron age. Another ancient alloy is brass, a mixture of copper and a small quantity of zinc.

During the last century and a half many more metals were discovered that could be produced in substantial quantities, chiefly due to improved methods of production, particularly owing to the availability of electricity and a vast development of chemistry and industrial chemistry. Some 70 metals are known at present, but some of these are still rare and very expensive so that about 50 are readily available as additional structural materials. You can easily realise what a vast field of investigation lies open before the metallurgists to study the innumerable alloys than can or could be made by mixing in various proportions two or more of these numerous metals.

At the same time the requirements of the modern structural engineers have increased enormously and have also become much more exacting. One great quality required at present is light weight, in particular for the construction of aeroplane-bodies, railway-carriages, motor-cars, etc. At the same time qualities of extra hardness, great strength and toughness are insisted upon. Take the case of high-speed aeroplanes. They are subjected to tremendous forces tending to bend and twist the wings and fuselages, or even to tear them to pieces. In the case of turbines making 15,000 or more revolutions per minute, it means that the blades are bent and shaken at every turn, and at the same time are stretched and tend to fly away under the action of the strong centrifugal forces. Then there is the heat problem, aeroplanes flying at very high speeds get heated to high temperatures due to the friction of air against the sides. This becomes even more acute in the case of missiles and rockets. At temperatures of 400°C. or more, ordinary metals become soft and lose a great deal of their strength; at the same time they are more easily attacked by various gases that may destroy them. The problems of heat and corrosion-resistance are even more pressing in the case of jet engines, when the fuel and air are burnt in the combustion chambers, and large quantities of white-hot gases are passing through the blades of a turbine which drives the compressors and also at times the propeller.

There are also the requirements of chemical industries which produce some extremely corroding chemicals; pipes and containers are needed that will be corrosion-proof even at high temperatures. The Atomic Power stations have problems of their own. At times metals like sodium or

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potassium, are used in the molten state as heat exchangers circulating around the uranium rods, so that pipes and containers are required that will resist the highly corrosive action of these molten metals. There is the further and very specific trouble of atomic energy: that the very radiations emitted during the fission process at times act in a very strong manner on the metals, greatly activating some of the corroding reactions. So now a new property, that of being radiation-proof, is required for metals used in atomic reactors.

We have listed quite a formidable array of special properties required in metals by our modern complex way of life, whether it be cheap and rapid transport, or the innumerable new-fangled products provided by the chemical industries, or the latest arrival, that of atomic energy. Of course metals and alloys are not the only answer to these exacting requirements, there are also the ceramics, and above all the plastics, to be explained later. Yet the fact remains that modern alloys provide the answer to most of the needs explained above, because, while complying with these special requirements, they still keep their own special properties, chiefly those of strength, of elasticity and workability.

We shall now briefly explain some of the more common alloys, starting from the ancient ones and showing how they were gradually transformed and improved.

Bronze. Copper is too soft for cutting purposes, but by melting copper with a small quantity of tin and after cooling we get a hard metal which can be shaped into cutting tools. Bronze is an alloy of copper and tin, in use since prehistoric times. It has been gradually improved, and quite a number of varieties of bronze have been produced by varying the proportions of copper and tin. At one end the copper percentage is as high as 98·25 with only 1·75% of tin, whereas at the other end there is 60% of copper and 40% of tin. As the percentage of copper decreases, the melting point is gradually lowered from 1,080°C. to 630°C. One interesting bronze is called bell-metal, containing 70 to 80% copper and 20 to 30% tin. It is specially valued for casting bells of good tones.

The bronze statues that have withstood the onslaught of weather for many years, and the bronze utensils and weapons uncovered by excavations after having lain buried in the earth for many centuries, are clear proofs that bronze is a good corrosion-proof alloy.

The properties of the different bronzes can be further varied and improved by the addition of small quantities of other metals. The addition of phosphorus greatly improves their strength, these phosphor-bronzes are very suitable for machine tools, turbine blades and gear wheels. A small addition of lead up to 2% improves the machinability of the bronzes.

Brass. This is another ancient alloy, which has been in use in India for many centuries, some household vessels made of brass having remained unchanged for the last 2,000 years.

Brass is an alloy of copper and zinc, the respective proportions of the two varying according to the special properties required. Brass is a hard and strong metal, it is corrosion-proof and easy to shape. The greater the proportion of zinc, the harder the metal becomes.

Because brass is easy to shape it has been freely used for ornamental work and structures, nowadays it is also used in large quantities for the marine and chemical industries. One snag is that it becomes mechanically weak at temperatures well below its melting point.

Solder. It is an alloy used for joining metals by applying molten solder to the ends to be joined. There is, of course, a great advantage in having a metal suitable for the purpose which has a low melting point. This is the special property of solders. The usual solder is an alloy of lead and tin, the melting point of the alloy is 183°C. which is much lower than that of the two component metals whose melting points are 317°C. and 232°C. respectively.

The proportions of lead and tin vary according to the two types of metal to be soldered, such as joining electric wires, lead pipes or machine parts.

Silver solders, or brazing solders, are copper-zinc alloys, with a small amount of silver to lower the melting point. They are used for joining copper, brass, silver and iron.

Steel. As iron is obtained by burning the iron ore with coal, it is natural that it should contain a certain amount of carbon, as also some other impurities present in the ore. In fact ordinary iron so produced may contain 4% carbon. By various processes the carbon content can be either increased or diminished, while other impurities are removed from the pig iron and thus we have steel, which means iron alloyed with a small percentage of carbon. The properties of steel vary with the carbon content and also with the particular type of heat treatment to which it has been submitted: slow cooling or rapid cooling or reheating etc. The hardness of steel increases with the carbon content, less than 0·1% of carbon giving extra soft steel, whereas high carbon steel used in manufacturing tools contains 1·05 to 1·2% carbon.

Steel is made very hard by the quenching process which consists in suddenly cooling red-hot steel by plunging it into cold water or oil.

Alloy Steels. These are steels which have been given special properties by the addition of one or more metals in various proportions.

Structural Steels. These are ordinary steels with small additions of a few other metals, such as chromium and nickel, which greatly increases their strength to withstand severe mechanical strains.

Chromium Steels. These contain large proportions of chromium, with small additions of nickel, molybdenum and cobalt. These steels show great resistance to heat and corrosion; stainless steel for cutlery contains up to 12% chromium; stainless and heat-resisting steel for engineering contains up to 18% chromium and 8% nickel.

By adding still more nickel and chromium these steels can be made to withstand high temperatures as in the case of jet engines, and highly corrosive chemicals.

Silicon Steels. These contain up to 18% silicon in cast iron. They resist the action of acids excellently.

Manganese Steels. These contain various amounts of manganese and small amounts of nickel, tungsten and vanadium. Such steels have great strength, hardness and toughness. They become harder on being hit.

Magnet Steels. In such steels additions of various metals provide either magnetic materials of high permeability and low resistivity, for cores of electric motors, generators or transformers, or strong permanent magnets; the latter contain in particular, aluminium, nickel, cobalt, hence the name alnico magnets.

High-speed Steels. These are extra-hard steels, containing up to 18% tungsten with smaller amounts of other metals; these steels retain their strength when very hot, and are used for making tools for cutting hard metals and alloys, in which process much heat is generated.

Light-weight Alloys. In many modern constructions lightness is an important factor, in particular in the case of aeroplanes and other fast moving vehicles, every ton of weight saved on structural material meaning more passengers or cargo or fuel. At the same time these light structural materials must also possess in a high degree the properties of strength, toughness, heat-and-corrosion-resistance.

Two of the lightest metals, which are readily available, and at reasonable cost, are aluminium and magnesium, being three to four times lighter than the common metals.

However, when in the pure state, they are rather soft and weak and therefore not suitable for structural work.

By alloying these metals with other metals in various proportions and giving them special heat treatment, cheap alloys are produced of great strength and toughness and other special properties, which are steadily replacing wood and steel in the manufacture of railway-carriages, lorries and even bridges.

Aluminium Alloys. These contain nearly 90% aluminium so that it remains light, the rest is made up of silicon and other metals in small quantities; silicon may be present up to 10-13% which greatly increases the strength of the alloy. The magnesium group of aluminium alloys contains a small amount of magnesium and a smaller amount of silicon, these alloys have medium strength but have high corrosion resistance. Duralumin, contains 3½% copper and ½% magnesium, and has great strength and toughness.

Magnesium Alloys. These contain 90% or more magnesium, with small amounts of zinc and (or) zirconium, the latter alloys have high mechanical properties and with small additions of other metals show a heat- and corrosion-resistance much greater than that of iron and steel. These alloys are amenable to the normal metallurgical forms of processing and are largely used in the construction of aeroplanes, portable tools, textile and consumer industries, etc.

Super-hard Alloys. The hardest alloys have no steel in them, they are made up of various proportions of some other metals. Tungsten carbide contains mainly tungsten, carbon and cobalt. Stellite contains tungsten, chromium and cobalt. These alloys remain hard and keep their strength even when red-hot, and are used in the making of engine valves, valve guides and machine tools.

There are some special bronzes, with a base of copper, which, in spite of their name, contain no tin; instead they contain some of the newer metals, such as zirconium, beryllium or also nickel. In beryllium bronze, a small amount of beryllium mixed with copper gives it a strength thrice that of mild steel. Nickel-beryllium alloys are among the strongest metal materials available at present.

Zirconium Alloys. These are some of the few materials that can resist the corrosion of the solid and liquid fuels used in rockets and guided missiles.

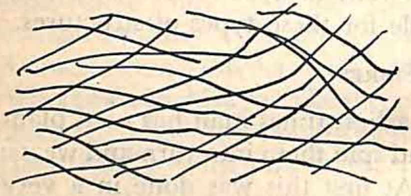
Radiation-proof Alloys. As mentioned above many of the ordinary structural materials are affected by the radiations emitted by the fission materials in the atomic reactors. Especially at the high temperatures prevailing in these reactors, the materials lose part of their strength and become less resistant to corrosion by the cooling liquids or gases circulating in the reactor. Zirconium, and tantalum alloys, and also beryllium, magnesium and stainless steels have been found specially suitable for these types of structures.

FIBRES

Natural Fibres. From earliest times man has used plant and animal fibres to twist and spin them into yarn and weave them into pieces of cloth. At first this was done in a very primitive and crude manner, but gradually more elaborate processes were evolved which turned out a great variety of finished products of greatly improved quality.

We take it for granted that natural fibres are available in great abundance, but just imagine for a while that they were not to be found in nature, that there existed only stone, metal, wood and various other things but none out of which you could extract fibres a few millimetres long. It would not be possible to spin yarn, to weave cloth or make ropes or make many other things which we find absolutely indispensable, things which were considered as such even in primitive societies. It is therefore worth while to know a little more about these fibres so indispensable for a comfortable way of living.

These natural fibres, whether cotton, or flax, or silk, or jute, or wool, or any other type of hair, when broken down by chemical methods are found to contain only the most ordinary elements grouped into molecules of one type or another. It is only since the last thirty-five years that scientists, by studying the natural fibres by means of X-rays, have been able to explain why fibres are really 'fibrous'. It was found in all cases that fibres consist of molecules very long in relation to their breadth. These long chain molecules are arranged nearly parallel to each other along the length of the fibre, they adhere to each other, are twisted together and overlap partly, the result being a fibre a few millimetres or centimetres long as we find them in nature.

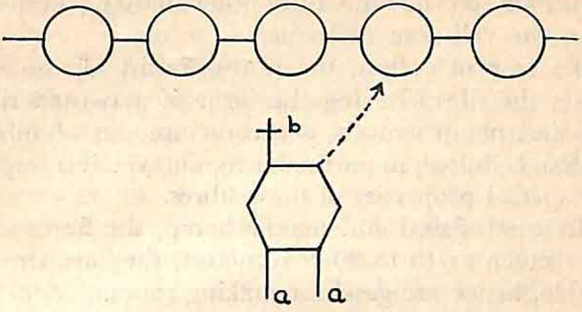


Fibres.
(*Highly magnified.*)

The two fundamental giant chain molecules forming the basis of most of the natural fibres are the cellulose molecules for plant fibres and the protein molecules for animal fibres.

Both the cellulose and protein molecular chains consist of simpler molecules with a free hook on each side so that they can link up with the next one, very much like a string of beads held together by little hooks. Each of these beads, or sub-units of the chain, is itself a rather complex structure of atoms or groups of atoms (branches) orientated in different ways. These side atoms or branches will of course play an important part in the adhesion between the molecular chains and will also otherwise affect the properties of a given fibre.

In both the cellulose and protein chain molecules the mainstay are the carbon atoms with their four available



Above: diagrammatis representation of long chain molecule.
Below: details of one bead in the chain.
a, side atoms; b, side branch.

links providing plenty of ways of continuous interlinking, extending over great lengths.

Plant Fibres. The cellulose molecule, which is the basis of most plant fibres, consists of a long chain of interlinked beads. Each of the beads consists of a few atoms of carbon, hydrogen and oxygen joined in a particular way, in fact it is a glucose molecule with a free hook at each side for linking up with the next bead. In natural fibres a cellulose molecule may consist of as many as 2,000 such beads, yet even then its overall length is still microscopic. As explained above, these long chain molecules are grouped lengthwise, stuck to each other, entwined and overlap so as to constitute a natural fibre a few centimetres long, or more, according to the varieties.

There are quite a number of different varieties of plant fibres all based on cellulose long chain molecules. The different properties of these various fibres depend on the particular shape of the constituent molecules, on the way they are grouped and twisted, on the adhesive forces between them and also on the amount of other matter (encrustation) between the cellulose molecules.

In the case of cotton, the fibres consist of almost pure cellulose, the fibres having the form of a twisted ribbon.

Flax and hemp contain a certain amount of substances other than cellulose, in particular lignin, which is responsible for the special properties of these fibres.

In the case of sisal and manila hemp, the fibres are very long, as much as 15 to 20 centimetres, they are strong and extensible, hence are good for making ropes.

Jute, kapok and coir have fibres which are nearly inextensible and brittle. This is due to a very high proportion of lignin between the cellulose chains.

Knowing the intimate structure of these fibres, methods have been devised to improve their qualities by treating them with special chemicals which will act on some of the atoms or branches of the beads or on the other substances present between the cellulose chains.

It is good to remember that the cell walls of all woods consist to a large extent of cellulose and lignin.

Animal Fibres. The basis of all animal fibres is one or other type of protein molecule. These are complex long chain molecules with a sort of repeat arrangement, which we have called beads; in the present case the special type of beads are called amino-acids, which have an extraordinary facility of linking up by a sort of head to tail fashion to form very long chains.

These constituent beads, called amino-acids, are themselves rather complex structures of a few atoms of carbon, hydrogen, oxygen and nitrogen, with occasionally a few other atoms like sulphur or iodine, etc. There are quite a number of different amino-acids, of a more or less complex nature, with side atoms and especially short or long side branches. This means that quite a number of different protein molecules can be built up by the combinations in different proportions of the various amino-acids; it is as if we were stringing up a set of beads of various colours, and this of course can be done in quite a number of ways. But in every case the protein molecules are truly giant molecules, their weights ranging from 17,600 to some six million. To have an idea what this means, compare with the corresponding weights of a water molecule which is only 18.

Even with such relatively great weights, the protein giant chain molecules are still very short, and it is by the grouping of a large number of them lengthwise and their sticking together, being twisted and overlapping, that they form the animal fibres as we know them.

Silk. This is produced by the silkworm to adorn its cocoon in which it will be eventually metamorphosed into a moth. Silk is formed by the extrusion of the contents of two glands through two tiny holes, the two filaments being glued together by an additional substance called seratin.

It is most probably in the process of extrusion that the long protein chain molecules arrange themselves lengthwise and form themselves into a continuous endless filament. The silk filament is a specially strong fibre, because the amino-acid beads making up the protein chains have in this case very short side branches, which makes it possible for the chains to be very closely packed. However, there are here and there a few amino-acid beads with longer side branches, this hinders somewhat the close packing, but on the other hand it is due to them, together with the imperfections in the packing, that silk filaments can be extended. Extension occurs by the straightening out of the molecules and even ultimately by the slipping of one molecule over another.

Hair. Examples of hair are wool, human hair, camel hair, fur fibres etc.

There are different types of animal hairs with rather greatly different properties, because the fibres are built up of different types of protein molecules and in various proportions. The main difference again comes from the difference in the amino-acid beads, constituting the protein chain molecules, especially the difference in the sulphur content, and also the difference in the side branches of the beads. In the case of animal hairs the side branches of the amino-acid beads are at times rather long and quite complex so that quite a number of cross links are possible between neighbouring molecular chains through these side branches. In this case also the essential structure of a hair results from the grouping lengthwise of a number of protein long chain molecules with the usual twisting, overlapping and adhesion between them.

When in the natural state, the molecules of the long protein chains are folded up in a compact form, but on stretching the fibre, the molecules unfold, and when the fibre is released, the molecules fold up once again. This successive extension and contraction is greatly facilitated by cold water, because water minimises the bonding between the side branches of the molecules. Wool resists creasing precisely because of the elasticity of its fibres.

However, as you well know, stretched or curled fibres, like hair, wool, etc., can be fixed and kept in that state by steam. The explanation is that heat breaks down some of the main links between the molecules, so that the fibre structure is relaxed; and further, when the fibre is thus stretched, new cross-linkages between the molecules are formed due to the heat, and so the stretching or curling is made permanent. This, of course, is the basis of 'permanent waving' of ladies' hair; however, at present there exist other processes than heat to break down the original bondings and rebuild others when the fibres are actually stretched.

A peculiar feature of hairs is that their outer surfaces have a special imbricated structure, like that of overlapping scales microscopic in size. On account of this, when animal hairs are rubbed lengthwise, especially in the presence of soap and acid, they all move in one direction and the structure shrinks.

In this manner a mass of these fibres can be squeezed into felt, or blankets or other heavy coatings. Of course in the case of laundering this is a serious defect, which, however, can be prevented by previously treating the wool with a low percentage of chlorine, so that the scale structure becomes inoperative.

Artificial Fibres. For several centuries people have been dreaming of imitating the silk worm in producing fibres, their main concern was to find a suitable viscous substance that could be drawn out into thin filaments. It was only towards the end of the 19th century that a practical way was discovered to realise this dream.

The process, greatly developed since then, and being still further developed and perfected nowadays, consists essentially in taking the long molecular chains of cellulose or protein provided by nature, realigning them and squeezing them together so as to obtain a filament of practically any desired length.

The main sources of cellulose are wood, which is the cheapest, or cotton. The main sources of protein are milk, casein or peanut and also corn.

Rayon. This is the best known and most commonly used artificial fibre, often referred to as artificial silk because of its smoothness and lustre, yet it is totally different from silk since it is based on cellulose and not on protein. One process of producing rayon (viscose process) consists in taking pure wood or cotton, chopping it up and making it into a pulp. This is dissolved in two chemicals resulting in a syrupy substance called viscose. After letting the viscose age for a few days, it is squirted under high pressure through a number of fine holes into an acid bath. The acid combining with the chemicals in the viscose leaves only the cellulose which solidifies into a very long thin filament. A definite number of these filaments are then twisted into a yarn, and further washed and conditioned into the required form for spinning and weaving. There exist several other methods of thus breaking up the wood or cotton pulp into the constituent cellulose molecules and then realigning and squeezing them into filaments. In this manner different varieties of rayon with different properties are produced.

In case the syrupy viscose, referred to above, is squirted under high pressure into an acid bath, through narrow slits instead of small holes, thin sheets of cellophane are produced. By other processes, chemists can also rearrange the cellulose molecules into 'blocks' resembling plastics, to which we shall refer later.

Rayon is a cheap substitute for silk, and is presently used for many purposes for which formerly natural fibres were used. It is specially used for women's and children's dresses, for linings of men's suits, for seamless hosiery, for curtains, draperies, upholsteries, bedspreads etc. Some rayon fibres have been made very strong and tough, and are used to make strong ropes and cords used in linings for tyres of aeroplanes and heavy lorries, for hoses and strong belts.

Protein-based Fibres. The more common ones are lanital from the protein of milk casein, and ardil from peanut-protein. Their composition is very similar to that of wool, except that the sulphur content is lower. The fibres are fine, warm and soft to touch like wool, in some cases the fibres are harsh and coarse according to the particular process of manufacture. The fibres are smoother than wool because each filament extends the whole length of the yarn. Whereas, wool being spun from the shorter fibres up to 15 cm. is never so compact, and is therefore bulkier and fuzzier giving it more compliance. As the ardil and lanital lack resiliency and have low wet strength, they are mostly used in combination with natural wool, the latter being more costly.

PLASTICS

Forerunners of Plastics: Paper, Rubber and Celluloid. In a crude and primitive form, paper has been in use for many centuries as a material to write upon. It is essentially a thin sheet composed of vegetable fibres spread out and compressed. The raw materials are cellulose fibres from cotton and linen, old ropes, esparto grass, straw, jute, bamboo, wood-pulp. The fibres are first isolated from foreign incrustant substances, by breaking and beating the fibrous material, by boiling and by chemical treatment, alkali or acid according to the fibre involved, and the type of paper to be produced. At this stage various mineral matters are added to impart special properties such as opacity, finish, substance, texture, good reception for printing etc. The pulp stuff thus prepared is spread out in thin sheets on wire sieves, and then, by hand or mechanically, these are pressed and squeezed to remove all moisture. The pressed and dried sheets are then further processed to give various degrees of finish and glaze, in particular by passing them through stacks of rollers, together with various ways of heat treatment.

It is probable that when Columbus landed in the new world he saw natives playing with rubber balls. Rubber is essentially a white sticky juice, called latex, exuding from cuts made in the bark of a special type of tree, called the rubber tree. This latex is collected and then made to coagulate by the action of an acid. The coagulate is passed through heavy rollers whilst washing it abundantly, and by further treatment with chemicals or by smoking, the rough product of raw rubber is obtained. To harden the rubber, and prevent it from becoming sticky at even moderate temperatures, a certain quantity of sulphur is mixed with the rubber. On heating the mixture some chemical reactions set in, which modify the structure and greatly improve the properties of rubber; this process is called vulcanisation and was discovered by Charles Goodyear, an American, in 1839. In case a large amount of sulphur, say over 15%, is mixed with raw rubber, the substance becomes quite hard and brittle, like vulcanite or ebonite.

It is only rather recently that the special properties of rubber were understood, when it was found that rubber consists of very long chain molecules with repeat units, from 150 to over 6,000 in number, these repeat units adding up head to tail in a very regular fashion. These long chain units with lateral adhesions between the chains, by overlapping form a well-knit unit exhibiting the special properties of rubber, in particular because of the special properties of the long chain molecules which can uncoil and coil up. The process of vulcanisation can also be explained on this basis: the sulphur mixed with the rubber when heated brings about reactions between the side branches of the long chains resulting in bondings between the lateral chains. This bonding will prevent the loosening of the chain molecules under the action of heat; the degree of rigidity thus introduced will depend on the amount of sulphur introduced.

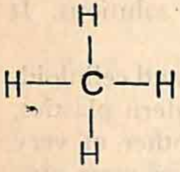
Celluloid is a synthetic material that has been manufactured since about 1875. Its basic material is cellulose, which is first transformed into cellulose nitrate, then mixed with camphor and ethyl alcohol. In this process, a number of chemical operations are involved. The three basic materials, with some minor additions of other substances, are mixed and kneaded together into a uniform mixture, then filtered, passed over heated rolls and pressed into blocks in heated hydraulic presses. The product is a heat-softening substance, therefore by heating it to about 100°C it can be moulded into various shapes which will be retained on cooling the material under pressure. It is thus made into sheets, or tubes, or continuous fibres. At ordinary temperature celluloid is hard and elastic, water-resistant and also resistant to dilute acid and alkali solutions. It is a highly inflammable material.

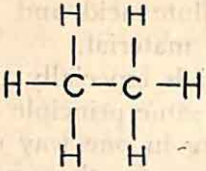
The above three materials, especially rubber and celluloid, are in fact based on the same principle as modern plastics, namely the close packing in one way or another of very long chain molecules. However, these substances were produced in an empirical manner without understanding the reasons why these synthetic substances exhibited quite special properties.

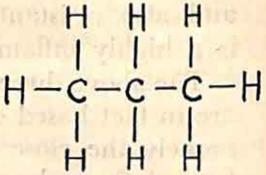
Giant Molecules, High Polymers. When studying fibres both natural and artificial, you have become familiar with the idea of long chain molecules which are the basic structures of these fibres. As this type of molecule has come to play such an important role in our modern way of life, in particular in the form of plastics, you should try to have a clear idea of the fundamental principles involved.

As explained in the case of fibres, these are made possible by the alignment, adhesion and entwining of a large number of long chain molecules. The main characteristic of these long chain molecules is that they are like a string of beads, they consist of a set of repeat units linked one to the other: side by side, or head to tail. In the case of protein molecules, the repeat unit was an amino-acid group of one type or another, in the case of cellulose molecules it was a glucose group. The chemists call these repeat units mere building blocks—monomers, meaning one part, whereas a chain of such units is called a polymer, meaning many parts, and if it is a very long, giant chain, it is called a high polymer.

Before going further you should know something of a third kind of long chain molecule found in great abundance in nature. These are molecules made up of only carbon and hydrogen atoms; thus one carbon atom with a hydrogen atom at each of its hooks is called methane, two carbon atoms


Methane.

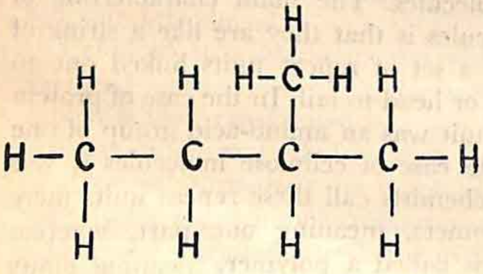

Ethane.


Propane.

with six hydrogen atoms arranged as shown in the figure is ethane, and so the chain is gradually lengthened.

A very interesting point about these chain molecules is that those with less than five units are gases at ordinary temperature, those with from five to twenty-five units are liquids, such as petrol, kerosene, etc., those with more than twenty-five units are solids, such as vaseline, paraffin wax, tar, etc. All these products can be obtained from crude oil by fractional distillation.

The above chains can also be given a more complex structure by giving them side branches as shown in the figure; some of the hydrogen atoms in the main chain or in the side branches can also be replaced by other atoms, like chlorine or nitrogen or fluorine, or by groups of atoms. Of course the properties of the substances will thereby be greatly modified, in particular a substance with chains of a shorter length may now be a solid.

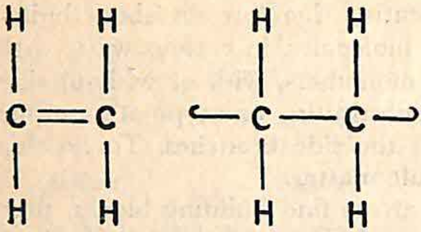

A chain molecule with side branch.

Synthetic Materials. Since nature is so efficient at making giant molecules which provide substances with many different properties, scientists must naturally feel inclined to imitate nature and even, if possible, to improve on nature's achievements. Scientists therefore set about building up artificial long chain molecules, in various ways, with various building blocks or monomers, with or without side branches, with or without substituting one type of atom for another in the chain or in the side branches. To do this proved to be a very difficult matter.

The two main problems are to find building blocks, that will readily join up, and to find an efficient method of bringing about this joining up of the repeat units. At first this was done by trial and error, but gradually methods were perfected when the actual processes taking place were better understood, as also the principles of the chemical reactions occurring in these transformations.

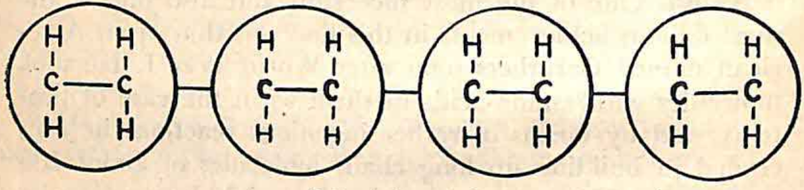
Nylon. One of the most successful and also one of the most famous achievements in this line was that of an American named Caruthers soon after World War I. He took molecules with amino-acids in them as in the case of proteins, and by means of rather ingenious reactions he succeeded in building up long chain molecules of about 100 repeat units. These were rather simple straight long molecules which could easily be arranged side by side lengthwise and would strongly adhere to each other, whilst being entwined and overlapping. As in the case of the production of rayon, here also this was realised by extruding, under pressure, the above molecules through a set of narrow orifices into cool air. In this way endless thin filaments were produced which were then spun together to produce the famous yarn called nylon. The original process of Caruthers was gradually improved upon in various ways, but the fundamental principle of producing synthetic fibres had been duly established.

Polythene. Another interesting example is that of polythene. Some ten years after Caruthers, two English scientists, took a quantity of a simple gaseous substance called ethylene, put it in drums under very high pressure and heated it to a

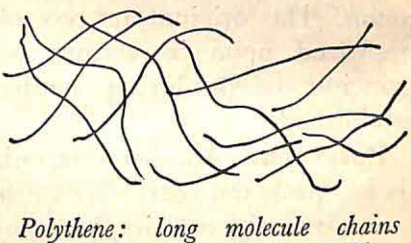


Left: ethylene molecule.
Right: ethylene with carbon bonds opened out.

very high temperature. When the operation was finished, on opening the container they found a solid white waxy substance, having some remarkable properties, in particular as regards waterproofing and electrical insulation. What had happened in the operation just described? The original gas ethylene, according to chemists, is built up of 2 carbon and 4 hydrogen atoms as shown in the figure. Note that the 2 carbon atoms hold each other by a double bond. In the process of heating, this double bond opened up, and then of course we have ready-made units to hook on to each other. This naturally was facilitated by the high pressure, bringing the units close to each other. The result is a very long chain of 200 to 1,000 repeat units called polythene which is a contraction of polyethylene, poly meaning many. These rather simple long chains can easily be arranged



Polyethylene chain.



Polythene: long molecule chains assembled in an irregular fashion.

lengthwise and squeezed together so as to produce another type of synthetic fibre. When the long molecular chains are jumbled up in an irregular manner they will still adhere to each other, and in this case will produce a solid which is the wide, waxy substance referred to in the figure on the previous page.

On heating a block of polythene, it gradually softens and finally turns to liquid. The reason is that the heat makes the chains expand and decreases the cohesive forces between the chains which gradually begin to move over each other as in the case of all liquids. Naturally, if polythene in the liquid state is squirted through a set of tiny orifices and issues into a cooling atmosphere, the plastic will freeze into thin filaments called fibres.

This is the general method of manufacturing man-made synthetic fibres such as nylon, polythene, terylene, orlon etc.

Plastics. Ever since the successful performance of Caruthers, scientists have been busy trying to build up long giant chain molecules, called high polymers, which on being squeezed together in one way or another, might produce various types of synthetic materials going by the general name of plastics.

They succeeded in building up quite a large variety of giant molecules. Some were quite plain with few, if any, side branches, like polythene described above. Others were built up with two or more different units, or beads, alternating in one fashion or another, like stringing up beads of two or more different colours. Other long chains were produced with some side attachments or substitutions, either plain atoms or groups of them, more or less complex, called side branches. Other chains were built which were found to have a twisted appearance, so that they could easily uncoil when pulled, and coil up when the tension is released.

Other chains were built up with such types of side branches that two or more such molecules could be firmly linked together by a chemical reaction between the ends of the side branches resulting in a firm bond between them. In other cases scientists tried to produce a sort of alloy by mixing together two different types of giant chain molecules.

On the other hand you should know that, at present, scientists have at least some forty different types of building units at their disposal which they can synthesise into giant chain molecules in the various ways just explained. You will easily realise then that the number of different plastic products that can be produced is very great indeed, and new ones are still being produced. Only those that show useful properties and at the same time are rather easy to make and are cheap, are selected for production on a commercial scale.

According to the length of the chains and their various properties it is possible to produce hard glass products, or squashy soft materials, or rubbery stuff, in particular with the chains that can coil up and uncoil. In case of chains that do not firmly interlock as explained above, when they are jumbled together they give a hard, glassy product as in the case of polythene, and, as we have said, when heated the stuff turns soft and finally liquefies. This type of plastic is called heat-softening or thermo-plastic. This is, of course, a useful property, when in the liquid state, these chains, if fit for it, can be squirted through orifices to make filaments, or they can be squirted through slits to make sheets, or they can be poured into moulds to make all sorts of objects, such as nylon combs, handles of toothbrushes etc.

In the case of long chains of which the side branches can combine to produce firm bonds between the chains, we have the other type of plastic called heat-hardening or thermo-setting. In this case the heat applied will no longer soften the substance or turn it into a liquid, because of the firm bonding between the chains. Such plastics therefore are to be used in the making of objects that will be exposed to great heat. To make such objects it is no longer possible to melt the plastic and pour it into moulds. In this case the raw materials, which by reacting on each other will produce this type of giant molecule, are mixed together and pressed into the moulds, then heat or pressure is applied, or other methods are used, to bring about the required reaction which will result in the thermo-setting plastics which thus will form in the very shape given by the mould.

Some of the more important properties of plastics are that many of them are waterproof because the fibres do not soak up water. Therefore nylon or terylene tents, or ropes or tarpaulins are really strong and lasting as they do not rot due to moisture. Nylon, polythene and quite a number of other plastics when made into thin sheets are excellent for use as insulating materials around electric wires and cables.

Perspex is a plastic glass formed of a heat-softening glassy plastic, and as it melts at rather low temperatures, it is easy to shape into different forms, even complicated ones, as required for windscreens or cockpit windows of aeroplanes.

Quite a number of plastics are heat-proof and corrosion-proof, so that they can be used to make containers and pipes for highly corrosive chemicals.

As we have already explained, these special properties of being heat-proof and corrosion-proof are realised by fixing on to the giant chains some special types of atoms or groups of atoms. Thus a famous heat-softening plastic going by the name of *P.V.C.* is an excellent insulator, and highly corrosion-proof against gases and many liquids, the *C* here stands for chlorine which has replaced the hydrogen atoms in the polyethylene chain.

Another special plastic, called Fluon or Teflon, is again nothing but a polyethylene chain in which the hydrogen atoms have been replaced by fluorine. Fluon is not a cheap plastic, but it is extremely corrosion-proof and very slippery.

The latter property is made use of when coating the metal of bearings with fluon. In this way the slipperiness of fluon dispenses with the ordinary lubricating oil. By applying fluon to skis it is found that they run nearly twice as fast.

Plastics, like the above and many others, are used in different ways like spreading, coating, etc. These plastics can be made squashy, soft or even into a paste, by mixing them with some liquid plasticizers such as oils or alcohols in which they are dissolved. After the paste has dried, the objects which had been dipped into it, are covered with a coating that is electricity-proof, or heat-proof, or rust- or damp-proof.

Silicones. One more class of plastics must be mentioned and it is that of silicones. These plastics are formed of giant chains which are based on the silicon molecule instead of carbon. Silicon is another element which is provided with four hooks to attach on to itself atoms or groups of atoms. Silicon is one of the commonest elements in the earth's crust, since on joining with oxygen it forms, with the metals, most of the rocks of the earth. After rather difficult and dangerous attempts, scientists have succeeded in building up long chains of repeat units based on the silicon element, and have thus produced quite a number of silicone plastics both heat-softening and heat-hardening. As silicon has the remarkable property that nothing sticks to it, silicone plastics are water-repellent and therefore are excellent for waterproofing. Silicone oils and silicone rubbers can stand up to both high and very low temperatures without practically any alteration in their properties. They are also slippery like fluon, and being 'non-stick' materials they are now often spread in a thin layer on the shell mouldings when objects are cast. After cooling, the moulded object can easily be removed from the mould because it does not stick to it, owing to the presence of silicone. In this way a mould can be used quite a large number of times.

Raw Products for Plastics. What are the raw materials used to produce the building units, the beads, which are then to be linked up one way or another to form giant chain molecules of various types?

Since most of the giant molecules are based on the carbon element as the mainstay of each building unit, it is not surprising that most of the raw materials are derived from the two main fuels, coal and oil.

As has been explained in Book 2, on burning coal to produce coal gas, quite a number of by-products are obtained such as ethylene, methane, ammonia, coal-tar and so on. These are some of the raw materials that are gradually transformed into different types of repeat units for building up giant chain molecules.

Oil is another abundant source of beads. As you know the crude oil coming from the oil wells is taken to oil refineries where, by fractional distillation, it is divided into a large number of different substances, some gases, some liquids, some solids, as explained above.

These substances again serve as the raw material for producing repeat units for the giant chain molecules. At times the rather long natural chains found in oil are first broken up into shorter units by heating in giant towers in the presence of an activating agent called a catalyst, hence the name 'cat-cracking' given to this process.

You see therefore that both coal and oil, besides being our most important fuels, are also of the utmost importance for providing raw materials for the ever-expanding plastic industries as well as for the manufacture of dyes and various other chemical compounds in great demand in our modern civilisation.

CHAPTER ACTIVITIES

Outdoors

Try to visit a plastic factory and a paper mill.

For your wall newspaper

Mount pictures of various articles made from plastics.

Note-book exercise

Make notes from newspapers and popular science journals on the value of synthetic materials in everyday life.

Laboratory work

1. Examine under a low-power microscope the various fibres of wool, cotton, jute, human hair, rayon, nylon etc.
2. Heat over a flame, or better, over an electric heater, bits of different kinds of plastics and find out if they are heat-softening or heat-setting.
3. Test the corrosion-resistance of some alloys and plastics by putting them in acids and heating the solution.

At home

1. Look around your home and list the various objects made of alloys or of plastics.
2. Gather specimens of different alloys and plastics and indicate their special properties such as hardness, elasticity, flexibility, heat-resistance and corrosion-resistance.

CHAPTER VIII

THE CHANGING WORLD OF LIFE

FROM the dawn of civilisation down to the present day, man has speculated on the origin of living things. Slowly, bit by bit, facts regarding this problem have been collected which have thrown much light on this thorny question. In this chapter we shall consider a representative sample of the evidence relating to the problem and also discuss a few of the important attempts, based on these facts, to give a satisfactory answer to the problem.

Evolution. Everything in the universe constantly undergoes change. The continual change and development as applied to the living manifestations of nature is called evolution. A large amount of evidence has accumulated which bears testimony to the fact that the living organisms in the world today have developed from those of bygone days by an evolutionary process. Although the facts concerning evolution are well established the question of what causes evolution is a problem that has not yet been completely solved.

Fossil Evidence. Scientists possess a fairly complete knowledge of animal and plant life as it exists today and also as it has existed in the comparative recent past. They also possess records of prehistoric life in the form of fossils that have been preserved through the ages of time. The actual remains of certain organisms that lived in temperate and cold climates have been found frozen in the ground. Fine details of structures such as muscle-fibres of animals and the cell-walls of plants have been preserved by petrification. This happened when an animal or plant was covered with sediment under water so that decay was prevented. In some cases the disintegration of an organism was followed by the filling in of the vacant spaces with a different substance which gradually hardened to rock. This resulted in a mould or cast of the animal.

According to evidence gleaned from the fossilised remains of animals and plants, scientists have estimated that life has existed on the earth for about a thousand-million years. This figure is based on the determination of the age of the lowest rock strata that contain remnants of living things. The approximate age of the fossils has been calculated by physical methods which fairly accurately determine the age of the rock strata in which the fossils have been found. In Chapter V you read of the element uranium which gradually changes to lead. As the rate of its transformation is known, the age of a rock stratum is calculated from the amount of lead and uranium present. Furthermore, the order in which a rock stratum occurs with respect to the other strata comprising the earth's crust also gives a rough idea of its age, the uppermost strata being the most recent while the deepest strata are the oldest. The layers of rock strata with the fossilised remnants of living things they contain tell us not only the order in which the various types of living things appeared on the earth, but also of the changes which have appeared within each type. Through a comparison of prehistoric forms with their descendants of today it is possible to trace the course of evolution in the past.

It is beyond doubt that life has developed from simple forms, that is, organisms with fewer and less efficient organs, to more complex forms, that is organisms with an elaborate organisation. The oldest rocks contain fossils of only the simplest organisms such as simple invertebrate animals. In the rock strata lying above we find not only the same kind of fossils as below, but also fossils of more complex invertebrates, such as lobsters and insects, and fossils of some lower vertebrates such as fishes and amphibians. In more recent rocks many of these fossils are repeated, although the species are not identical with those found in earlier rocks. In these rocks, fossils of reptiles are to be found for the first time.

The evidence is conclusive of the fact that mammals are the most recent products of the evolutionary process while man is the last of the mammals to come into existence. A further interpretation of fossil records tells us that man has taken the longest time to reach his present level of complexity.

A study of fossilised plants preserved in rock strata tells us very much the same story as it did in the case of animals, namely, that there has been a progression from simple life to complex, the changes occurring very slowly over a period of a thousand-million years.

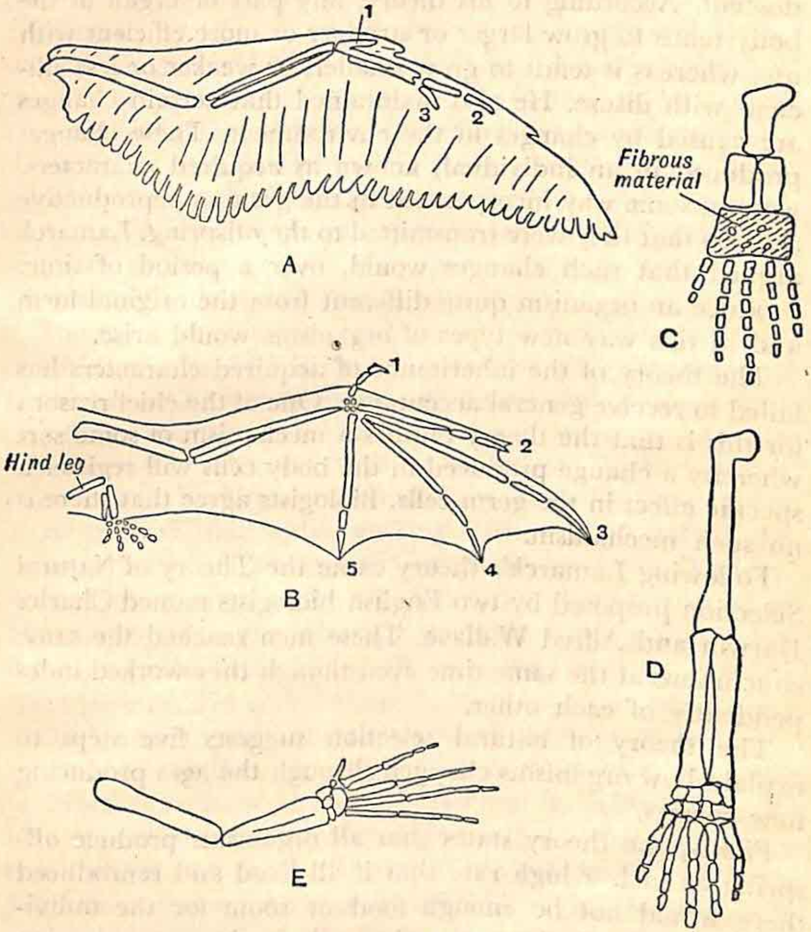
Geographical Evidence. A careful study of the distribution of animals over the face of the earth affords further proof of evolution. Evidence from such study reveals that certain types of animals have originated in definite centres and thereafter by means of air, water, land and even other organisms, have spread to neighbouring regions with varying environments. Through the course of centuries many of these animals became isolated from the central localities through barriers of various kinds. Gradually they developed differences from their ancestors, in form, structure or behaviour, which led to the origin of new types of creatures. For example, the one-humped Arabian camel is well adapted to the environment in which it lives, while the two-humped Bacterian camel living in more northerly regions has developed shaggy hair which protects it from cold weather. Both animals arose from a common ancestor and through the centuries have now become suitably adapted to the environment in which they live.

Australia had none of the higher type of animals such as horses, oxen, sheep, pigs or rabbits until these were introduced into the country by man. The most reasonable explanation for this fact is that the land bridge once connecting the country with Asia was broken before the higher mammals had evolved. It is for the same reason that the mammals of Australia are distinct from the rest of the world.

Anatomical Evidence. Anatomy is a part of biology dealing with the structure of animals and plants. A comparative study of the structural organisation of the organ systems of different animals affords some of the strongest evidence of evolution. Such comparisons reveal structures whose presence can only be explained by evolutionary relationships. For example, in man the appendix is a vestige of an extension of the large intestine, it is small and functionless, whereas in some mammals the appendix is much larger and has an important digestive function. A vestigial structure shows definitely that the organism possessing it has undergone evolutionary change. At one time such a structure was of some service to the organism but, due to some change in the environment, it has fallen into disuse and gradually degenerated.

A comparison of the forelimbs of such vertebrates as men, whales, bats, birds and frogs shows that even though this organ is used for different purposes, it is built on the same general plan: one bone in the upper limb, two in the lower limb, several tiny bones in the wrist or its equivalent and a few long bones corresponding to the hands and the fingers. A comparison of other parts also shows similar resemblances. Such similarities indicate that the vertebrates had a common ancestor in the distant past whose descendants gradually changed their bodies through the years that followed.

Historical Theories of Evolution. The fact of evolution is well established, but the question of the underlying forces or causes which bring about evolutionary changes is a subject on which agreement is not quite general. There are



Comparison of forelimbs.
A, bird; B, bat; C, whale; D, man; E, frog.

three main theories that have been proposed as an explanation of the process of evolution.

A French biologist named Jean Lamarck advanced the theory that new species come from preceding species by descent. According to his theory, any part or organ of the body tends to grow larger or stronger or more efficient with use, whereas it tends to grow smaller, or weaker or less efficient with disuse. He also maintained that certain changes are caused by changes in the environment. These changes produced in an individual, known as acquired characters, were in some way incorporated in the germ or reproductive cells, so that they were transmitted to the offspring. Lamarck argued that such changes would, over a period of time, produce an organism quite different from the original form and in this way new types of organisms would arise.

The theory of the inheritance of acquired characters has failed to receive general acceptance. One of the chief reasons for this is that the theory implies a mechanism of some sort whereby a change produced in the body cells will register a specific effect in the germ cells. Biologists agree that there is no such mechanism.

Following Lamarck's theory came the Theory of Natural Selection proposed by two English biologists named Charles Darwin and Alfred Wallace. These men reached the same conclusions at the same time even though they worked independently of each other.

The theory of natural selection suggests five steps to explain how organisms changed through the ages producing new species.

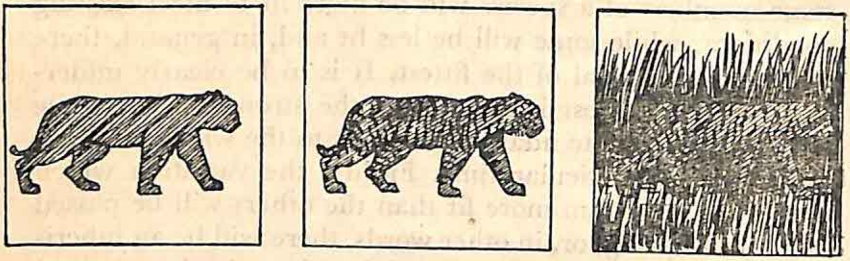
Firstly, the theory states that all organisms produce offspring at such a high rate that if all lived and reproduced there would not be enough food or room for the individuals of even a single species. Secondly, such overproduction would lead to a struggle for existence among individuals of the same species and between those of different species, as well as between organisms and the factors of their physical environment. Thirdly, the theory points out that all members of a species vary from each other in many small ways. Fourthly, the theory states that as a result of such variations some members of a species will be more fit to meet existing conditions, while some will be less fit and, in general, there will be the survival of the fittest. It is to be clearly understood that by fittest is not meant the strongest, but those that are best able to adapt themselves to the whole environment at that particular time. Fifthly, the variation which makes one organism more fit than the others will be passed on to its offspring, or, in other words, there will be an inheritance of variations. Thus the origin of species is governed by means of natural selection.

The chief weakness in this theory is that only some kinds of variations can be inherited. Apart from this, the theory of natural selection has stood the test of time and in the present day forms the core of modern theories of evolution.

A few years after the death of Darwin a Dutch botanist named Hugo De Vries propounded the Mutation Theory. De Vries noticed that while working with a plant called the evening primrose, new species suddenly appeared. The environment was in no way responsible for these new species. Moreover, when the new species were crossed they were found to breed true, that is, the offspring were exactly like their parents. He called these sudden changes mutations.

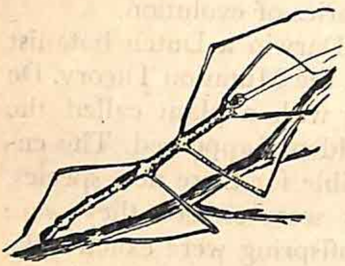
De Vries put forth the mutation conception of evolution to account for the emergence of new types of species. He modified the theory of natural selection by substituting the idea of mutation for the idea of the origin of variations as a result of use and disuse. By doing this the theory of natural selection became: overproduction, struggle for existence, mutation, survival of the fittest, inheritance of mutations. This modified theory of natural selection is accepted by most biologists today.

Adaptations. Many organisms show astonishing adaptations to their environment and possess special structures which fit them to their environment. The stripes on the coat of a tiger enable it to follow its prey without being seen. The



How a tiger blends into its natural surroundings.

chameleon has a wonderful power of changing its colour to suit the colour of the plant on which it rests. The stick insect resembles the twig of a plant in its appearance and by remaining quite still it deceives its enemies. The giraffe has a long neck which enables it to reach the leaves on the topmost branches of a tree. There are countless such adaptations in the animal kingdom.



A stick insect.

In the plant kingdom too, there are countless remarkable adaptations which are useful to them in the environment in which they live. Certain plants are equipped with climbing organs, called tendrils, which enable them to twine around the trunk of a tree and pull themselves upwards to the light. Plants living in desert regions have water storage tissue and various other adaptations to resist drought. Many plants possess thorns which protect them against destructive agents.

The mutation theory claims that adaptations are chance mutations which occurred and which made the organisms in

A climber on its way to the light.

which the mutations appeared, called mutants, especially well fitted to their environment. There are harmful mutations too. Such mutations handicap organisms to such an extent that they may fail to grow to maturity and die leaving no offspring.

Heredity. We are all familiar with the commonly observed biological fact that 'like begets like'. We should be very surprised indeed if a female cat had a litter of puppies. We are also aware that offspring resemble their parents, and that children of the same parents resemble each other far more closely than unrelated children. Moreover, children of the same parents show differences among themselves: they show some characteristics found in the father, some found in the mother, some which are intermediate between the two, and some that are shown by neither the father nor the mother. To understand such phenomenon we must study heredity which deals with the resemblances and differences exhibited by organisms related by descent and also includes the mechanism involved in the perpetuation and transmission of characteristics from one generation to the next. Since, in nearly all animals and plants that reproduce by sexual means, a newly formed organism develops from the union of two germ cells derived from parents of the opposite sex, we must first study these germ cells or gametes as they are called.

Gametes. Among flowering plants, a male gamete from the pollen cell fuses with a female gamete in the ovule. The process of fusion of these two dissimilar gametes is known as fertilisation. Among animals and men too, fertilisation is the process of fusion between a male gamete, called a sperm cell, and a female gamete, called an ovum or egg cell. During fertilisation the nuclei of the two gametes join and a single cell is formed, called a zygote or fertilised ovum. After fertilisation, the zygote develops into an embryo which is the tiny beginning of a new organism.

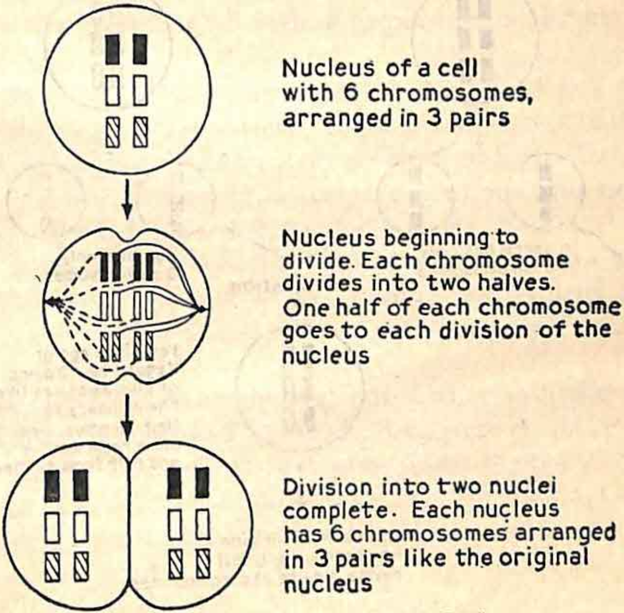
Gametes possess the potentialities of the characters which are to be seen in the newly formed individual. They are, so to speak, the tiny protoplasmic bridges which span the interval between the immediate generation and the following one and are the means of transmitting characters from the present to the future generations.

Chromosomes and Genes. After fertilisation the zygote divides into two cells, then four, and so on, until the millions of cells are formed which go to make an organism. If the division of cells is studied under the microscope it is seen that just when a cell is about to divide into two, the protoplasm of the nucleus begins to divide into a number of separate tiny rods of protoplasm called chromosomes.

Chromosomes contain a set of heredity units called genes.

These genes are peculiarly adapted to carry and transmit heredity factors that will transmit traits to following generations. Genes cause the various characteristics to appear in an organism. Thus, for example, in the case of human beings, a gene may cause curly hair, and another may cause brown eyes and so on.

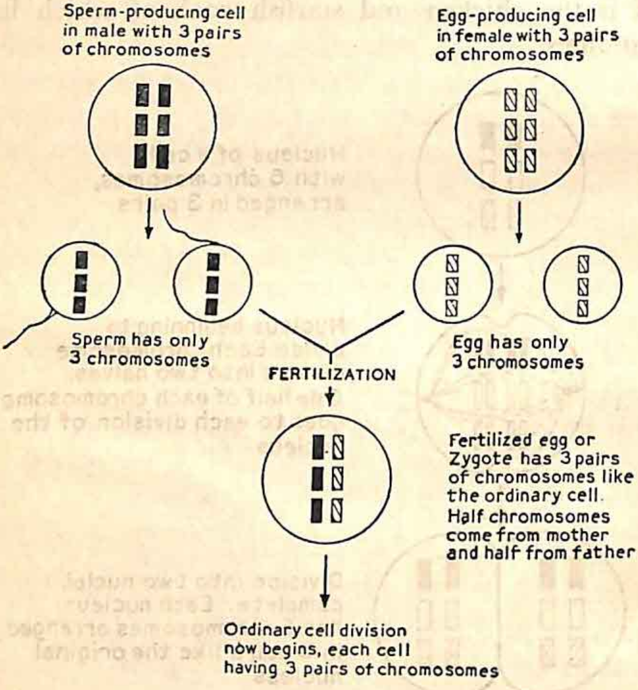
All the cells in the body of a particular species or organism possess a definite number of chromosomes, but the gametes of the organism have only half the number of chromosomes. The number of chromosomes varies according to the type of organism. Thus, in man, the number is always 48, in a mouse it is 40, in the rabbit it is 22 and so on. Some organisms have the same number of chromosomes, an example of this is the chicken and starfish each of which has 18 chromosomes.



How the nucleus divides in ordinary cell division.

Chromosomes are arranged in pairs, each chromosome having a homologous mate like itself in size and shape and which contains similar genes. The chromosomes which determine sex, however, are an exception to this.

In the cell division of a body cell each chromosome splits lengthwise into two and each new cell resulting from the division receives the full number of half-chromosomes which then develop into full ones. In this way the two new cells have not only the same number of chromosomes as the parent cell, but also the same number of genes as the parent cell. Consequently, as an organism grows and the number of body cells multiply, the body keeps the same unalterable


Sperm-producing cell in male with 3 pairs of chromosomes
Egg-producing cell in female with 3 pairs of chromosomes
Sperm has only 3 chromosomes
Egg has only 3 chromosomes
FERTILIZATION
Fertilized egg or Zygote has 3 pairs of chromosomes like the ordinary cell. Half chromosomes come from mother and half from father
Ordinary cell division now begins, each cell having 3 pairs of chromosomes

To show what happens when sperms fertilise egg-cells.

characteristics because each new cell exactly reproduces the characteristics of the cell from which it was formed.

Gametes, however, are formed so that the chromosomes are shared, not split as in the case of body cells. Consequently, each gamete has only half the number of chromosomes of a body cell, that is, one set. During fertilisation, when gametes of opposite sex fuse together, the full number of chromosomes is restored to the zygote. In this manner each parent equally contributes a full set of hereditary units to the character of the offspring by means of genes in the gametes. Thus the new organism which grows from a fertilised cell has some of the characteristics of both parents.

Mendelism. Long before we had any idea of chromosomes or genes, an Austrian monk, named Gregor Mendel, discovered by breeding experiments the heredity of peas.

Mendel observed that there were two kinds of pea plants in his garden: a dwarf variety, about a foot and a half high and a tall variety, about six to seven feet high. He *self-pollinated these plants for several generations and noticed that the offspring always showed the same character as the parents in regard to size, that is, the tall plants always had tall offspring, while the dwarf plants always had dwarf offspring. Mendel said that these plants 'bred true' and were 'pure'.

Mendel next *crossed the tall pea plants with the dwarf pea plants. He collected the seeds that were produced and planted them. The plants that grew from these seeds were all of the tall variety. Mendel said that the character tallness in peas was dominant over dwarfness, while the character dwarfness which did not show at all in the offspring was recessive. In the same way he crossed pea plants that produced green seeds with pea plants that produced yellow seeds and found that since all the offspring had yellow seeds, the character yellowness was dominant while the other, greenness, was recessive. After many other similar experiments he formulated his first law, known as the law of dominance, which states that when two organisms which differ in one character, are crossed, the dominant character dominates or hides the recessive character.

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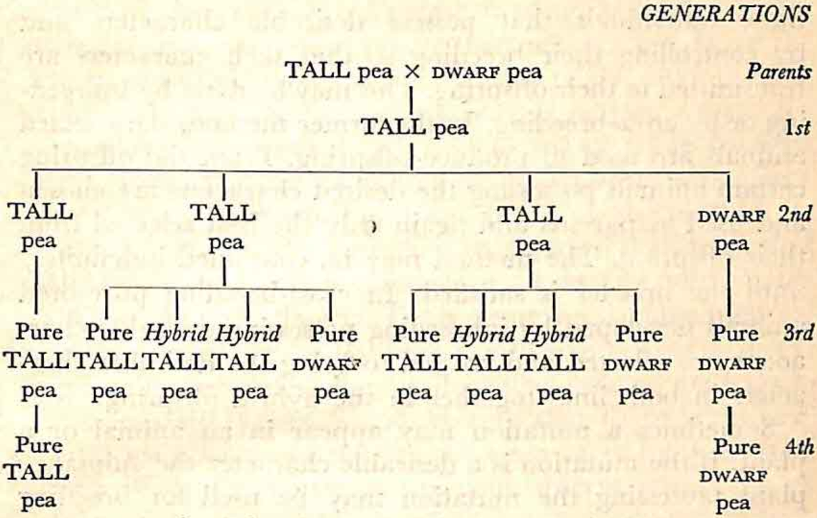
* An account of how this is done is described in *Chapter Activities*.

Mendel continued his experiments of the tall and dwarf varieties of pea plants. He worked with the first generation of offspring, that is, the tall pea plants he had obtained when he crossed pure tall plants with pure dwarf plants. Although this first generation of plants were as tall as one of their parents, they were hiding the character of dwarfness. Such plants are called hybrids. He crossed these hybrid tall plants and when their seeds were collected and planted he noticed that the plants produced were both tall and dwarf plants. He then formulated his second law, known as the law of segregation, which states that when hybrids are crossed with each other or self-pollinated, the recessive character separates, or segregates, out again in some of the offspring. In this second generation of offspring, Mendel noticed that for every dwarf plant there were three tall plants. He therefore concluded that about one-fourth of the offspring of mating between hybrids show the recessive characters. He next worked with the second generation of offspring. He crossed the dwarf plants of this offspring with each other and obtained pure dwarfs. He then crossed the tall plants of this second generation of offspring with each other and found that one-third of the plants were pure talls, while the remaining two-thirds were hybrid talls. These hybrids always produced tall and dwarf plants in the same proportion of one pure tall, two hybrid talls and one pure dwarf.



Many years after the death of Mendel, scientists took note of his discoveries and proved that the laws discovered by his breeding experiments with peas were almost universal in the plant and animal kingdoms. The name Mendelism has been given to the laws in honour of the discoverer.

Practical Applications of Mendelism. Knowledge gained through a study of Mendelism has been of universal importance to man in the breeding of living things, particularly in the production of new and improved varieties which provide food.

Food plants that have such desirable characters as a natural resistance to insects or disease or drought, or which give a high yield per acre, are selected and developed by cross-breeding. Decorative plants are also developed by cross-breeding. Breeders attempt to combine in one particular plant all the desirable characteristics of the many separate breeds of that plant. New varieties which have certain desired characters are also obtained by cross-breeding.

Animals also have been improved by the selection of those individuals that possess desirable characters and by controlling their breeding so that such characters are transmitted to their offspring. This may be done by inbreeding or by cross-breeding. In the former method, the selected animals are used to produce offspring. From the offspring certain animals possessing the desired characters are chosen and used as parents and again only the best selected from their offspring. The method may be continued indefinitely until the breeder is satisfied. In cross-breeding pure-bred animals developed by inbreeding possessing desirable characters are selected and crossed to bring the desirable characters in both lines together in the hybrid offspring.

Sometimes a mutation may appear in an animal or a plant. If the mutation is a desirable character the animal or plant possessing the mutation may be used for breeding purposes and since mutations can be inherited, further varieties of plants and animals can be produced.

CHAPTER ACTIVITIES

Outdoors

Visit a museum and study specimens of prehistoric life. The collection of fossils will be of special interest to you.

For your wall newspaper

Collect pictures of prehistoric animals which once inhabited the earth and mount them on your board.

Note-book exercises

Write short notes on the following subjects: (*a*) how animals defend themselves, (*b*) how plants defend themselves, (*c*) how any named animal is specially adapted to fit into its environment.

At home

If you have a garden at home you can verify Mendel's laws, but you must be prepared to spend several years on your experiments. Select plants that are annuals. Cross the flowers of two plants of the same species which differ in some striking character such as flower colour or seed colour. To cross plants, say a red flowered plant with a white flowered plant collect pollen by hand or by means of a feather from the stamens of the red flower and put it on the pistil of the white flower, or you can do the reverse, that is, collect pollen from the stamens of the white flower and put it on the pistil of the red flower. To prevent cross-pollination by natural agencies cover the flower with paper bags after you have pollinated them and tie the open ends of the bags to the stems with string. To make sure that there is no accidental self-pollination remove the stamens of the pollinated flower. Keep careful records of your observations.

CHAPTER IX

DISEASE AND HOW TO FIGHT IT

WHEN all the organs of the body are in good condition, when they are functioning smoothly and harmoniously with each other, the body is said to be in a state of good health. If, on the other hand, the normal functioning or well-being of one or more organs is disturbed, the balanced working of the body gets disorganised and the body becomes diseased.

Hippocrates, a Greek physician regarded as the father of medicine, as early as 400 B.C. believed that disease was caused by an over-production of a substance called black bile in the body, and various attempts were made to remove the substance from the body. Two thousand years ago, people thought that disease was caused by evil spirits entering the body. Consequently magic and witchcraft were used in an attempt to drive out evil spirits. Various childish notions that have been associated with disease still exist today, such as outdoor night air causing certain kinds of diseases, and so on.

Much progress has been made during the last two centuries to solve problems concerning the cause of disease and its prevention. Through medical research we now know the ways in which the body protects itself against the various factors that cause disease and how we can assist it in its fight against disease. However, much work remains to be done in this connection and there are still many diseases about which hardly anything is known.

Pioneer Work. A Frenchman named Louis Pasteur was the first to make a study of tiny one-celled plant organisms, called bacteria, which were so small that a microscope had to be used to see them. He proved by experiment that there were bacteria in the air that brought about decay. His experiments in this connection suggested to him that bacteria might be responsible for some diseases and for the putrefaction of wounds. About the same time a German doctor named Robert Koch demonstrated that certain kinds of bacteria were the cause of tuberculosis and cholera. By the end of the nineteenth century he and his co-workers had discovered the bacteria which cause diphtheria, typhoid, plague and many other diseases. Since the time of Koch many of the bacteria that produce various kinds of dangerous diseases have been discovered.

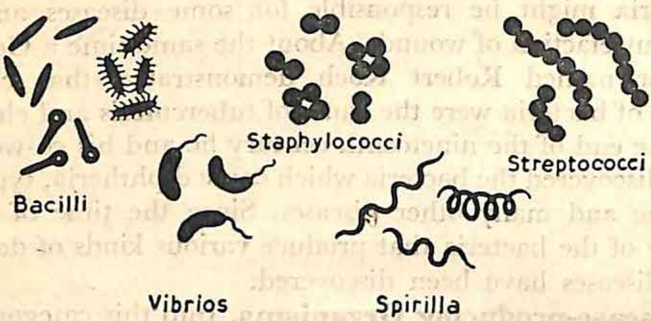
Disease-producing Organisms. Into this category fall the micro-organisms, parasitic organisms and poisonous organisms.

Micro-organisms that cause disease, commonly referred to as 'germs' or 'microbes', may belong to any one of three main groups: the viruses, the bacteria and the protozoa.

The causative organisms of certain diseases such as the common cold and influenza are viruses. They are so small that they cannot be seen even with the most powerful compound microscope. Recently, however, a few of them have been made visible by the aid of the electronic microscope. Viruses can pass through the membranes of body cells. Unlike many micro-organisms, however, they cannot grow outside living cells.

Bacteria are tiny one-celled plants. They are called plants because they have a firm cell wall of cellulose. Like their near relations, the fungi, these plants also do not possess chlorophyll.

Bacteria are found in the air, in the soil, in the water, in living things, in fact almost everywhere. They live on either dead or living material. A few kinds of bacteria live at the expense of our bodies. They may enter our bodies through the nose, mouth or a break in the skin. When bacteria find a suitable situation in which to live and feed, they begin to multiply. A bacterium multiplies by asexual reproduction, that is, by merely splitting into two, and into two again, and



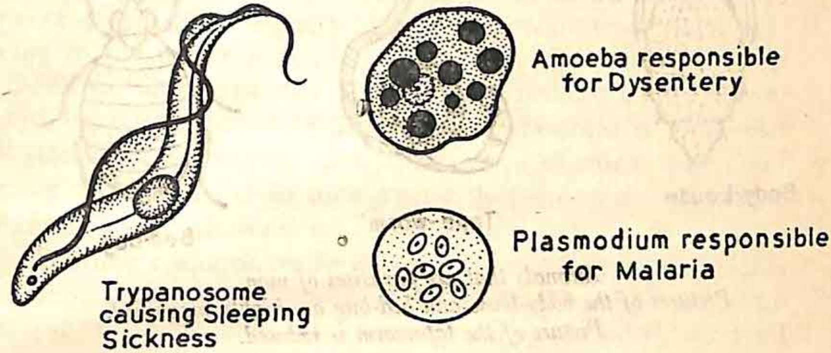
Bacteria causing disease in man.
(Highly magnified.)

so on with amazing rapidity, until there are millions of them. Some bacteria destroy tissue while some produce poisons, called toxins, which cause illness. Certain kinds of bacteria, called cocci, are shaped like tiny spheres. Some cocci which appear in long chains, called streptococci, cause sore throat and tonsillitis; other cocci which appear bunched together, called staphylococci, cause boils, abscesses and blood-poisoning. Bacteria that are oblong or rod-like in shape, called bacilli, cause typhoid, diphtheria and tuberculosis. Other bacteria in the shape of curved rods, called vibrios, cause cholera. Spiral-shaped bacteria, called spirilla, are also disease-producing bacteria.

You have read of protozoa in Book II. Some of these cause diseases.

A scientist named Ronald Ross who was born in India and did much of his research here, discovered that the female Anopheles mosquito was the carrier of plasmodium, the protozoon which caused malaria. Another protozoon, a certain kind of amoeba, feeds upon the walls of the large intestine and causes dysentery.

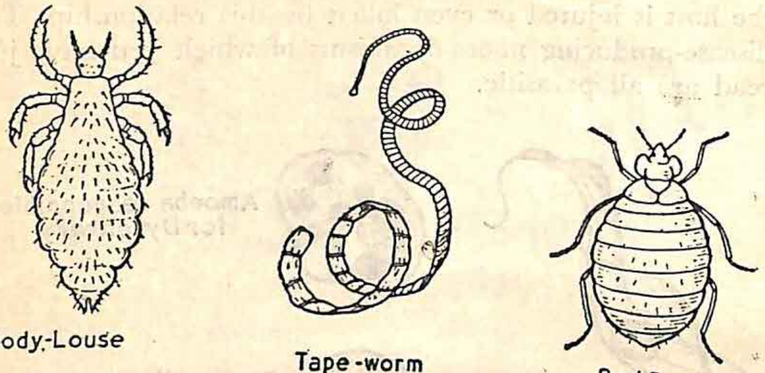
Parasites are those organisms that live and feed on or within the body of a living being called the host. Frequently the host is injured or even killed by this relationship. The disease-producing micro-organisms of which you have just read are all parasitic.


Amoeba responsible for Dysentery
Plasmodium responsible for Malaria
Trypanosome causing Sleeping Sickness

Protozoa causing disease in man.
(Highly magnified).

Certain multicellular plants, notably members of the fungi family, cause disease. The fungus causing ringworm destroys the skin cells and releases a substance that causes a ring-like eruption.

The most common parasitic animals that cause disease are insects and worms. The bed-bug, the head-louse, the body-louse and the flea are insect parasites. These unpleasant creatures, usually found on dirty people and in dirty houses, feed by piercing the skin of a person with their jaws and then sucking his blood. If they have been feeding on the blood of a person infected with some disease, they may inject these germs into their next victim. These insects are usually associated with the carrying of certain disease-producing bacteria. The body-louse, for example, is a carrier of typhus fever. Fleas are especially dangerous, for they can carry the bacteria that cause bubonic plague from a rat suffering with this disease, to a human being.



Body-Louse

Tape-worm

Bed-Bug

Animals that are parasites of man.
Pictures of the body-louse and bed-bug are highly magnified.
Picture of the tapeworm is reduced.

A well-known insect parasite which carries disease micro-organisms is the mosquito. There are several kinds of mosquitoes. The Aedes mosquito carries yellow fever, the Culex mosquito carries dengue, while the Anopheles mosquito carries malaria.

Among the parasitic worms are the tapeworm, the hookworm and the roundworm.

There are several kinds of tapeworm: one kind lives in the cow and another kind lives in the pig. If a person eats the infected meat of these animals which has not been sufficiently cooked, the larvae or embryos of these worms which are in the meat are swallowed along with the meat. Once these arrive in the body they develop into full-grown worms which feed on the digested food passing through the intestines.

The hookworm starts life in the soil and enters the skin of the foot of a person walking barefooted. It then enters the blood stream, bores through the lungs, passes up the windpipe and finally enters the intestine by way of the oesophagus. Here it pierces a blood-vessel and secretes a substance which keeps the blood from clotting and thus has a steady flow of blood on which to feed. The loss of blood from the blood-vessel causes the infected person to suffer from anaemia.

One type of roundworm, of pinkish-grey colour (Ascaris) is most common, especially in small children. The female lays great quantities of eggs, which, when swallowed, find their way to the upper part of the intestine where they develop to full size in one month. The eggs are present in the faeces, and infection occurs by means of contaminated food and water. To prevent infection by this type of worm, night-soil must be disposed of in such a way that the eggs and larvae cannot reach the food or drinking water.

Another common type of roundworm is white (Trichiniasis). In the adult stage it inhabits the small intestine of pig, rat and man. The female, when settled in the wall of the intestine, produces embryos which are carried by the blood to the various muscles, where they remain coiled up in cysts. These encysted larvae may remain there in that state for years. In the case of man the life-history of the worm ends at this stage, but in the case of the pig, if the undercooked flesh infested with these cysts is eaten by man, or another animal, the larvae in the cysts develop rapidly into full-grown worms, and stay thus in the intestine for a short time.

To prevent the entry of parasitic worms into our body it is essential that we eat well-cooked food. Various drugs are also available to rid the body of these worms.

Poisonous animals include certain kinds of snakes and scorpions. These creatures inject a poisonous substance into the body of their victim. The snake injects its poison through two special teeth called fangs, while the scorpion injects its poison through its tail.

Certain kinds of plants are poisonous. Some cause illness which may result in death when they are eaten, while others cause inflammation when they touch the skin.

Diseases Not Caused by Organisms. You have already read in Book III of diseases such as rickets, pellagra, beri-beri and scurvy that are caused by the deficiency of certain vitamins in the diet. These diseases are called deficiency diseases.

Diseases such as diabetes may be caused by the improper functions of certain body organs. One of the chief functions of the liver and the muscles is to remove excess sugar from the blood and store it. These organs require a sufficient supply of one of the body hormones called insulin in order to do work. (A hormone is defined as a chemical product of an organ which is carried by a fluid of the body, such as blood or lymph, to another part of the body where it stimulates a certain activity.) Insulin is secreted by the pancreas. Some people suffer from a deficiency of insulin. In such cases the body cannot store sugar, and the result is a disease known as diabetes. Nowadays this disease can be controlled by insulin injections.

Cancer is caused by the abnormal growth and division of the cells of any organ or tissue of the body. If the consequent swelling, called a tumour, is harmless, it is said to be benign, and it can usually be removed by a surgeon. In other cases, however, a tumour is malignant and gives rise to cancer.

How We Can Aid the Internal Defences of the Body. The body is provided with an ingenious system of defences against the millions of disease micro-organisms that attack it every day. Some of these micro-organisms that gain entry into the body are killed by various chemical substances produced in the body, while others are devoured by the white corpuscles of the blood.

As micro-organisms grow in the body they may produce poisonous substances, called toxins. Each kind of micro-organism produces its own kind of toxin which may either remain within the micro-organism or leave it. In either case however, the toxin produced harms the body. If the toxin produced leaves the micro-organism, the body cells make a chemical substance called an antitoxin to neutralise it.

This antitoxin will only neutralise a certain kind of toxin and no other. The mere presence of micro-organisms, moreover, stimulates the body to produce other chemical substances called antibodies which work against the micro-organisms. Among the antibodies are substances which dissolve bacteria, substances which inactivate bacteria so that they can easily be consumed by white corpuscles, and substances which sensitise and stimulate the white corpuscles to more energetic destruction of the micro-organisms. When a person recovers from certain diseases such as the common cold, diphtheria, typhoid and smallpox, his body cells have produced enough antibodies to protect him against the harmful effects of the disease and he is said to be immune to the disease. His immunity may protect him against a recurrence of the disease for only a few weeks as in the case of the common cold, or for several years as in the case of smallpox.

The inborn power of resisting disease possessed by a body is called natural immunity, whereas that acquired during a person's lifetime is called acquired immunity. The latter kind of immunity may be active or passive, according to the way in which it is developed. Active immunity may be acquired through actually contracting the disease as just described; or it may be developed by the use of a substitute for the virulent micro-organism causing the disease in the form of an antigen.

Virulent bacteria or viruses that have been weakened or killed so that they have lost their power to stimulate the body to produce antitoxins are used as antigens. Antigens introduced into the body are instrumental in causing it to produce antibodies to combat the antigens and thereby create an immunity to the disease caused by the living virulent bacteria and viruses of the same type. Immunity against tuberculosis and typhoid is achieved by the injection of such antigens into the body.

Toxins produced by bacteria may also be used as antigens. Before such toxins are introduced into the body they are first rendered harmless by special chemical treatment. This treatment, however, does not cause them to lose their power to stimulate the production of antibodies in the body. Immunity against diphtheria can be conferred on an individual by the introduction of such chemically treated toxins into his body.

The process of injecting antigens into an individual in order to develop immunity is called vaccination and is quite safe as it does not cause the person to develop the disease.

Passive immunity may be acquired by the introduction of antibodies into the body. A specific antigen is injected into the bodies of animals such as cattle or horses which causes these animals to build up an antibody. Then blood serum containing the antibodies is taken from these animals and injected into the human body thus giving it immunity against the specific antigen. Immunity against diphtheria can also be built up this way.

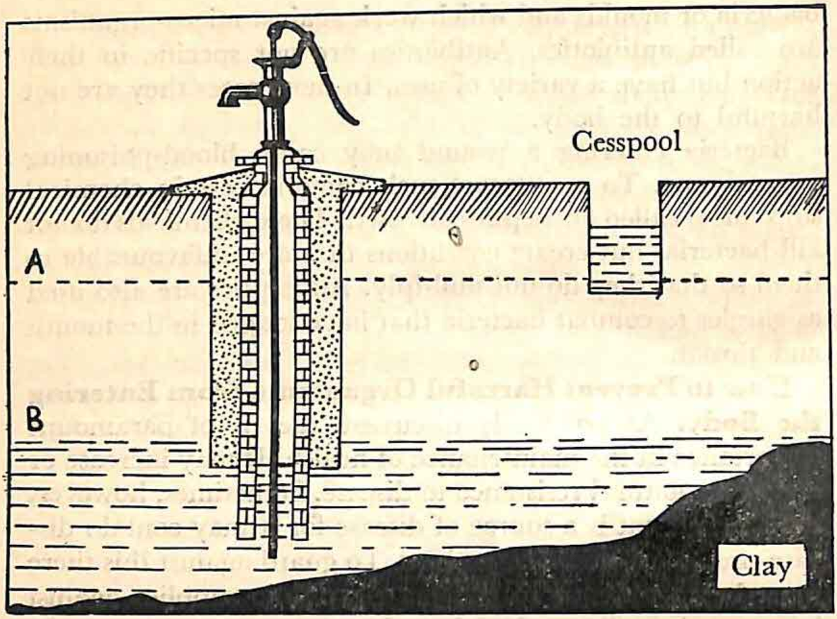
To help the body counteract poisons from the bites of snakes certain substances are inoculated, or injected into the body. Poison is obtained from a particular snake and is injected into the body of an animal whose body produces antitoxin to neutralise the poison. Thereafter the blood serum containing the antitoxin is taken from this animal and used to inoculate persons who have suffered a bite from this particular snake.

Certain kinds of chemicals such as paludrine, atabrine and sulpha drugs are used to treat diseases caused by micro-organisms. Chemical substances obtained from moulds, notably penicillin, streptomycin, aureomycin and chloromycetin have proved successful in treating tuberculosis, pneumonia, influenza and many other diseases caused by bacteria or viruses. Such substances which are made by bacteria or moulds and which work against micro-organisms are called antibiotics. Antibiotics are not specific in their action but have a variety of uses. In most cases they are not harmful to the body.

Bacteria entering a wound may cause blood-poisoning or gangrene. To counteract such bacteria certain chemical substances called antiseptics are used. These chemicals do not kill bacteria, but create conditions that are unfavourable to them so that they do not multiply. Antiseptics are also used as gargles to combat bacteria that have lodged in the mouth and throat.

How to Prevent Harmful Organisms from Entering the Body. As previously discussed, diet is of paramount importance in the maintenance of health. It may increase or lower our natural resistance to disease. Sometimes, however, the food we eat is a source of disease for it may contain disease-producing micro-organisms. To guard against this there must be regulations to protect the public supplies against insects such as flies and cockroaches that carry micro-organisms. Establishments handling food and drink must be licensed and regularly inspected by competent persons to insure that the establishment and the staff employed meet high standards of cleanliness and health. Slaughter-houses must also be inspected to insure that diseased animals are not sold as a source of food.

The supply of water for drinking and domestic purposes must be plentiful and clean. Sources of water must be frequently inspected and a constant vigilance must be maintained to protect their purity. Chlorination, filtration and proper storage give protection against water-borne diseases such as typhoid and dysentery. In rural areas the usual source of water-supply is a well. A well must be constructed of brick, with the top and sides protected by concrete or clay. Sometimes, however, during heavy rains there is sudden rise of ground water and the ground water



To show how a well constructed of brick with its top and sides protected by concrete may be contaminated by a near-by cesspool.
A, level of ground water after heavy rains.
B, ordinary level of ground water.

entering a well may become contaminated by seepage from near-by farmyards, outdoor toilets, or cesspools. For this reason water from even the best constructed wells must be frequently tested for possible pollution.

Milk may convey the micro-organisms of tuberculosis, typhoid, diphtheria and many other diseases. To guard against these diseases the production and handling of milk must be carefully supervised. Cattle must be regularly tested for tuberculosis; milking and the handling of milk must be carried out under sanitary conditions and all milk must be pasteurised. The process of pasteurisation readily destroys the disease-producing organisms carried by milk.

The process consists in either heating the milk to a temperature of 160°F. for one minute, or heating the milk to about 150°F. for 30 minutes, and then rapidly cooling it to 50°F. or less. Pasteurisation does not destroy the food value of the milk. After milk has been pasteurised it must be quickly delivered to the consumer in sealed containers.

To protect the community against the diseases of an infected person, his clothing, materials handled by him as well as the clothing and person of anyone coming into contact with him or with objects which the patient has handled, must be rendered free from disease micro-organisms. Anything that kills micro-organisms is called a disinfectant, while the process of using a disinfectant to destroy disease-producing micro-organisms is called disinfection.

Disinfectants can be divided into three groups: natural, physical and chemical. Sunlight and fresh air are natural disinfectants that kill most disease-producing micro-organisms. Intense heat is a physical disinfectant. Heat is employed in various forms to kill micro-organisms. In the case of many micro-organisms even the temperature of boiling water is not enough to kill them. Certain metallic objects are passed through a flame or boiled under pressure. Contaminated articles of no value are burnt. Contaminated clothes, bedding etc., are disinfected by boiling for a period of about half an hour. Chemical disinfectants may be liquids such as phenol, potassium permanganate solution and carbolic acid, or gases such as sulphur dioxide or chlorine. When disinfectants are used in the form of gas and vapour the process is called fumigation.

In recent times great care is taken during a surgical operation to keep bacteria away from the operating theatre. Cleanliness is the watchword during operations. Instruments are sterilised with steam so that they are free from bacteria. The theatre is kept spotlessly clean, while doctors and nurses wear clean clothes and wear masks over the mouth and nose to prevent any bacteria being breathed out on to the patient. Surgery practised in this way is called aseptic surgery.

Many harmful micro-organisms and the eggs of intestinal worms leave the body with the wastes. Since these continue to live in human wastes and other kinds of refuse, it is vital that provision be made for the safe disposal of refuse, otherwise they may find their way into wells or may even be brought on to food by carriers such as house-flies.

In rural areas, cesspools and septic tanks are generally constructed for the disposal of human wastes. In places where outdoor toilets are constructed, care must be taken to ensure that such toilets are lined with concrete so that they can be easily cleaned at regular intervals. They must also be covered so that flies cannot enter them. Chloride of lime must be frequently added to the contents of the pit to control unpleasant odours.

Cities usually dispose of human wastes by a system of underground drains called sewers which are led into large bodies of water far from bathing beaches and drinking water-supplies. House refuse must be put into metal covered dust-bins that are situated at some distance from the house. Refuse must be regularly collected from dust-bins by municipal refuse carts or lorries and burnt at some distance from the town or deposited on waste or low-lying lands or used to fill up excavations or processed for producing manure.

Some kinds of diseases spread directly from one person to another. It is therefore extremely important to isolate individuals who are infected with such diseases. The separation of persons suffering from such a disease, from other persons, in such places and under such conditions as will prevent the direct or indirect conveyance of the micro-organisms causing the disease to susceptible persons, is called isolation.

Among the diseases to which man is susceptible are many which he contracts from small animals. Chief among such animals are house-flies. These insects breed among garbage and filth. It is, therefore, of vital importance to keep your house and surroundings clean. Food must be covered with muslin or kept in special wire-mesh cupboards.

A chemical known as *D.D.T.* is used very extensively to kill mosquitoes. It is sprayed by men carrying special knapsacks which contain this chemical. In places that are badly infested with the pest, aeroplanes are often used to fly over the area and spray the ground below with *D.D.T.* Oil is sometimes used instead of *D.D.T.* It is sprayed over a tank which contains mosquito larvae. The larvae cannot breathe the air dissolved in water as the fishes are able to do, but instead must rise to the surface to breathe. The oil covers the surface of the tank causing the larvae to die of suffocation. In some tanks, fishes that eat mosquito larvae are introduced.

Rats must be destroyed as they may become carriers of the micro-organisms causing bubonic plague. This disease is transmitted to man by the bite of infected fleas. We must keep our body and the clothes we wear clean at all times. Lice which carry the micro-organisms causing typhus, live and breed on dirty people.

Common Diseases and Epidemics. In the broadest sense, diseases may be divided into two main groups, communicable and non-communicable. The former group includes those diseases caused by micro-organisms which are transmissible either directly or indirectly from one person to another; while the latter group includes those which are the result of inherited or acquired, structural or physiological defects. Communicable diseases are also referred to as contagious diseases. When a communicable disease, such as plague or malaria, is always found in a certain area, to a greater or lesser extent, it is said to be endemic. If, however, a disease, such as influenza, spreads from place to place, it is said to be epidemic.

Communicable diseases may be spread by the air, as in the case of the common cold, influenza, pneumonia, tuberculosis, diphtheria, or by water and food as in the case of cholera, typhoid, dysentery, or by insects as in the case of malaria, kala-azar, typhus and plague, or by direct contact as in the case of ringworm and scabies.

The Common Cold. This disease is merely a condition of inflammation of the lining of the nose and throat due to infection by a micro-organism. The exact nature of this micro-organism has not yet been discovered. Epidemics of the common cold occur chiefly during the winter months on account of the fact that severe cold, chilling and dampness lower the resistance of the body tissue and consequently it is readily susceptible to an attack by the micro-organisms causing the disease. The symptoms are a burning sensation and a heavy flow of mucus from the nose. Accompanying this is a headache, aches and pains in the back, shivering and a slight temperature. The disease may last for a few days or persist for a longer period. The treatment of a cold must never be neglected as it may lead to serious complications such as pneumonia and even tuberculosis. Preventive measures include avoidance of crowded and dusty places, the wearing of suitable clothing and choice of a healthy diet. Seriously infected persons should remain in bed and secure the services of a physician.

Influenza. This disease is caused by a virus that gains entry to the body through the nose. The factors that favour infection are overcrowding, fatigue and a dusty atmosphere. The disease lasts only a few days. The symptoms are chill, fever and pains in the head, back and limbs. Influenza must be treated promptly and with care as it may spread to the lungs and cause pneumonia. Preventive measures include avoidance of crowded and dusty places, overwork and fatigue, and choice of suitable clothing. Gargling with a weak solution of potassium permanganate should be done regularly.

Pneumonia. This disease is a state of inflammation of the lung substance which results in the air cells becoming obstructed. This, in turn, interferes with normal breathing and thus the blood does not get enough oxygen. The disease is caused by a certain kind of bacteria. It is characterised by rigors, cough, headache and high temperature. Severe cold and a low resistance of the body tissues may cause a person to contract the disease. Preventive measures include an avoidance of draughts, undue exposure and the wearing of suitable clothing. Treatment should be carried out under the direction of a physician.

Tuberculosis. This disease is also caused by bacteria. It is characterised by fever, a general wasting of the body and certain other special symptoms depending on the part of the body which has become affected. The bacteria may attack any part of the body: when the lungs are affected the disease is known as phthisis or consumption and when the lymphatic glands of the neck are affected it is called scrofula.

Bacteria entering the body through breathing infected air may settle on the tonsils and thence make their way to the lungs or the lymphatic glands of the neck. Tuberculosis of the alimentary canal is caused by bacteria entering the body through the mouth as the result of drinking from an infected cup or eating food infected by flies and dust or drinking infected milk. People that live constantly exposed to infected persons are liable to contract the disease. The bacteria that cause tuberculosis are readily killed by exposure to sunlight, moist heat and acids; in the dry state, however, they can retain their vitality for a very long time. A large number of bacteria leave the body of the patient in his expectoration and once the sputum becomes dry the bacteria are spread in the air as particles of dust. Patients must therefore spit into spitoons containing carbolic acid. Millions of bacteria are also spread through the air by means of droplets or infected spray from the mouth or nose of the patient when coughing, sneezing or speaking loudly. Patients must use paper handkerchiefs which are immediately burnt after use. All objects used by the patient must be kept separate and sterilised frequently.

Everyone has at some time or other breathed in tuberculosis bacteria and eaten food contaminated by them. Insanitary conditions such as lack of sunlight and fresh air, overcrowding, poor ventilation, exposure to dusty atmosphere help to increase the vitality of the bacteria or lower the resisting power of the body against them. Furthermore, weakness due to previous diseases, overwork, worry, chronic starvation, intemperance and early marriage increase the susceptibility of the individual to the disease.

Tuberculosis can be prevented by educating the masses in the elementary laws of hygiene, so that they may realise the importance of sanitary conditions, increase the vitality of their bodies and its resistance against the bacteria. Patients must be properly treated and care taken that the infection is not transmitted to others. In recent years *B.C.G.* vaccine given to children has proved successful in preventing the development of the disease in later life.

Diphtheria. The symptoms characteristic of this disease are fever and sore throat, with the formation of a membrane in the upper respiratory tract, which in later stages obstructs the air passage and causes death from suffocation and heart failure. The disease is chiefly prevalent among children between the ages of 2 and 5. Infection is spread by droplets of saliva sprayed from the nose and mouth during coughing or sneezing, or indirectly through the objects handled and used by the patient. Persons convalescing from the disease may harbour bacteria for a long time and start fresh epidemics. Patients must be isolated and objects handled by patients must be disinfected. Children must be immunised by inoculation.

Cholera. This disease is characterised by vomiting, purging, cramps, collapse and the suppression of urine. Infection occurs from another cholera case and is generally indirect, through the use of infected water for drinking, bathing, or other domestic purposes, or through the adulteration of milk with infected water, or through the contamination of food. The bacteria causing the disease are conveyed to water and food through the improper disposal of sewage. Particular care must be taken in disposing of the wastes from a patient, and his clothes must be boiled in water or put into carbolic lotion before being passed on to the laundry. The essential methods for protection against the disease consist of inoculation, pure water supply and clean food, careful disinfection of clothes, efficient conservancy and control of flies.

Typhoid. This disease is sometimes known as enteric fever. It is characterised by fever of about three weeks duration, a tenderness of the abdomen, constipation or diarrhoea. The bacteria causing the disease are present in the faeces of the patient and in his sputum, not only during the attack but also for several weeks after the fever has left him. The processes of infection and also the methods of preventing the disease are the same as in the case of cholera. The most common means by which the typhoid bacteria are transmitted is through milk and water. Immunity against the disease, which lasts for about a year, can be conferred on a person by inoculation.

Dysentery. This is the name given to a group of diseases which are characterised by mucus, or mucus and blood in the faeces accompanied by severe pains in the abdomen. The different varieties of the disease are caused by both bacteria and protozoa. The type caused by the former is acute while that caused by the latter is chronic in its course and is often characterised by an abscess on the liver. Factors causing dysentery are poor food, insanitary conditions, famine, exposure to cold, fatigue, indigestion, overcrowding and weakness resulting from previous infections. The processes of spread and the preventive measures adopted are the same as in the case of other water-borne diseases.

Malaria. The protozoon causing malaria is conveyed from an infected person to a healthy person through the agency of the mosquito. The symptoms characterising the disease are repeated attacks of fever accompanied with shivering and a feeling of cold which ceases after profuse perspiration. If untreated, successive bouts of malaria may lead to a distension of the spleen, pigmentation of the face, anaemia and general debility. Since the mosquito is responsible for this disease, preventive measures include destruction of the mosquito and control of its breeding places. A drug called paludrine has, in recent years, been used very successfully in treating the disease.

Kala-azar. This disease is characterised by a distended spleen, pigmentation of the skin, emaciation and anaemia. The disease is transmitted through the agency of an insect called the sand-fly. This insect breeds in cracks in the walls and therefore such cracks must be sealed and walls must be kept in good repair. The insecticide *D.D.T.* has proved successful in exterminating sand-flies.

Typhus. Although the micro-organism carrying this disease has not yet been identified, it is known to be carried by the louse. The disease is characterised by headache and pains in the back, in some cases a rash appears on the abdomen, chest and shoulders. The patient usually becomes very ill and may fall into a state of stupor. Preventive measures include cleanliness of the person and clothing, and a thorough disinfection of clothes and bedding used by the patient.

Plague. This disease is caused by bacteria conveyed from infected rats to man through the agency of fleas. If the bacteria causing plague are introduced into one of the superficial blood-vessels, they directly enter the blood stream and produce the septicemic form of plague. If they are introduced into other parts of the body they move along the lymphatic vessels and attack the lymphatic glands before entering the blood stream. This causes the superficial lymphatic glands to swell and this variety of plague is called bubonic plague. Preventive measures against this disease are chiefly concerned with the extermination of rats, the construction of rat-proof houses and inoculation against the disease. Another variety of plague called pneumonic plague is caused by the same bacteria causing the other varieties of the disease. In this case, however, infection is through droplets of sputum during coughing or expired air and has nothing to do with rats or fleas.

Ringworm. This disease is caused by a parasitic mould. The mould generally attacks the hairy portions of the body. The disease is characterised by a severe itching. Since the disease is very contagious, great care must be taken in disinfecting combs and towels used by infected persons.

Scabies. This disease is caused by a tiny parasitic insect called the itch mite. It not only feeds on the surface of the skin but also burrows under it, causing great irritation. If the itch mite has burrowed under thick skin a fine raised line is seen; if it has burrowed under thin skin oval spots and watery blisters are formed. The disease is treated by rubbing sulphur ointment on the infected parts. Preventive measures include a thorough disinfection of the patient's clothes and bedding.

CHAPTER ACTIVITIES

Outdoors

Visit (*a*) a modern dairy farm, to see what sanitary precautions are taken to prevent the contamination of the milk; (*b*) the public health department, to see what is being done to control disease in your town; (*c*) a food market, to see how food is protected against contamination.

For your wall newspaper

Obtain statistical data for various diseases from the Medical Health Officer of your town. Prepare graphs showing the incidence of each disease year by year.

Note-book exercise

Prepare a report describing the battle for health in your town.

Laboratory work

When we attempt to grow or cultivate bacteria we are said to be making cultures of bacteria. To prepare cultures of bacteria we must first prepare food for them. Pour 100 c.c. of water into a beaker and then add 1·5 gm. of powdered agar, or gelatine, 1·0 gm. of peptone, 1·0 gm. of Bovril, Oxo or meat broth, and 0·5 gm. of common salt. Heat the mixture and stir it until all the agar has dissolved. Now add sufficient bicarbonate of soda to change a piece of red litmus paper to blue when dipped in the mixture. Filter the mixture while still hot, through thick absorbent cotton lining a funnel, into a clean beaker which has been previously sterilised. Cover the beaker at once. Pour the liquid into two shallow dishes such as watch glasses or Petri dishes which have been previously sterilised. Cover both dishes immediately. After the culture medium has set solid in both dishes, remove the lid of the second dish and expose its contents to the air for about 3 minutes and then cover it. Leave the dishes for about 2 days in a warm, dark cupboard. You will find that the culture medium in the second dish is covered with a number of dots or tiny irregular patches. Each of these represents a colony of bacteria which have arisen from the multiplication of bacteria that fell upon the culture medium during its exposure to the air. Examine some of the matter forming these spots under a microscope. You will see thousands of bacteria. The culture medium in the dish which was kept covered throughout the experiment will be free from bacteria.

At home

Consult books in your science library and prepare notes for a class symposium on 'Famous Scientists in the Fight against Disease'.

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